NBS TECHNICAL NOTE 1025

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Interactive Fortran IV Computer Programs for the Thermodynamic and Transport Properties of Selected Cryogens (Fluids Pack)

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INTERACTIVE FORTRAN IV COMPUTER PROGRAMS FOR THE THERMODYNAMIC AND TRANSPORT PROPERTIES OF SELECTED CRYOGENS [FLUIDS PACK]*

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The thermodynamic and transport properties of selected cryogens have been programmed into a series of computer routines. Input variables are any two of P, ρ or T in the single phase regions and either P or T for the saturated liquid or vapor state. The output is pressure, density, temperature, entropy, enthalpy for all of the fluids and in most cases specific heat capacity and speed of sound. Viscosity and thermal conductivity are also given for most of the fluids. The programs are designed for access by remote terminal; however, they have been written in a modular form to allow the user to select either specific fluids or specific properties for particular needs.

The program includes properties for hydrogen, helium, neon, nitrogen, oxygen, argon, and methane. The programs include properties for gaseous and liquid states usually from the triple point to some upper limit of pressure and temperature which varies from fluid to fluid. Computer listings of the FORTRAN IV codings are presented. Copies of the programs may be obtained from either the Thermophysical Properties Division of the National Bureau of Standards at Boulder, Colorado, or from Walter Scott at the NASA-Johnson Space Center in Houston, Texas.

Key Words: Argon; computer programs; density; enthalpy; entropy; equation of state; heat capacity at constant pressure; heat capacity at constant volume; helium; hydrogen; methane; neon; nitrogen; oxygen; thermal conductivity; velocity of sound; viscosity.

1. Introduction

Recent technological developments which made possible personal interaction with large computer systems by remote terminal has proved to be a real advantage in situations where immediate response to requests for data are important. This computer program was developed in response to a need for thermodynamic and transport property data in an interactive mode. The program makes possible the

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acquisition of thermodynamic and in some cases the transport properties of seven different cryogenic fluids. Those fluids are: hydrogen, helium, neon, nitrogen, oxygen, argon, and methane. All of the properties are calculated from empirical equations which are derived from the existing experimental data via weighted least squares fit of mathematical models to those data. The reader who is interested in the details of the correlations is referred to the sources cited for each fluid in the sections to follow.

Five of the fluids (hydrogen, nitrogen, oxygen, argon and methane) utilize the same mathematical model of the equation of state, and four of the fluids (nitrogen, oxygen, argon and methane) utilize the same correlating function for the transport properties. No transport properties for hydrogen, or neon, are given. Using the same functional form for the properties of several different fluids greatly simplifies the computer programs, since all that is needed to switch from one fluid to another is a different set of coefficients to the equations.

The properties of helium and neon are calculated from empirical functions which are different than those of the other five as well as each other. The addition of these two fluids represents approximately half of the total length (core storage) of the entire program.

The programs have been written with a dual purpose in mind. As has already been mentioned the primary purpose is to make available to the user in an interactive mode, the thermodynamic and transport properties of selected fluids. The second purpose is to provide the necessary subroutines to the user who has a very specialized need. Therefore the program has been written in a modular form which allows the user to extract almost any combination of fluids and properties.

The remainder of this report includes a section devoted to each fluid and an additional section describing the general part of the program.

2. Uncertainty of the Calculated Properties

When calculating thermodynamic properties from an empirical equation of state, one should be aware of certain problem areas where it is difficult to estimate realistically what the uncertainties really are in a given property. In the critical region ($\rho_c \pm 0.2\ \rho_c$ and $T_c \pm 0.05\ T_c$), the calculated density may be in error by several percent, while the calculated pressure or temperature will not be as inaccurate. Specific heat capacities and the thermal conductivity in

the critical region become very large values and no realistic estimate of the uncertainty may be made. Saturation boundaries, gas, liquid and solid are potential areas of large uncertainties for derived thermodynamic properties, especially heat capacities. In the compressed liquid, calculated pressures will have an uncertainty of several percent. This is a consequence of the nature of the surface and is in no way the fault of the equation of state.

In each of the following sections on the individual fluids, uncertainty estimates will be given for that particular fluid. These estimates have been obtained from the source documents and do not reflect the potential large uncertainties of the problem areas outlined above.

3. Computer Routines

The thermodynamic properties produced by the computer program listed in Appendix A are all calculated using a mathematical model of the equation of state of the fluid and classical thermodynamic relationships. The reader who is interested in the thermodynamics and mathematics of the problem is referred to McCarty (1975). Table 1 lists all of the subprograms with pertinent information for each.

In general eleven or twelve significant figures need to be carried in the property calculations to insure no round off errors in the result, and sample values for checking performance are included in each of the sections on the properties of a particular fluid. Performance should be checked periodically when running on a time-share system.

The program, once executed, leads the user through a series of input requests and the use of the program should be self-explanatory after the particular system requirements for access and execution are satisfied.

Upper and lower pressure and temperature limits have been imposed on each fluid according to the range of validity as claimed by the original source document. The lower pressure limit is an indication of where the program fails due to the limitations of the computer calculations. All of the functions reduce to the ideal gas in the limit of zero pressure but because of some terms in the equation which have very large exponents, the iterative solution for density fails at very low pressures. Because these models are empirical and cannot be trusted to give even reasonable results outside their ranges of pressure and temperature, the user is cautioned not to change the pressure and temperature limits originally set in the program.

4. Conclusions

The preparation of this program has demonstrated the utility of maintaining functional form when modeling properties of several different fluids. With a single functional form, the change from one fluid to another becomes a matter of switching constants and even more important the addition of more fluids to the scope of the program becomes very simple.

The author wishes to acknowledge the support of NASA, without which this work would not have been possible, and in particular the support and encouragement of Walter Scott at the Johnson Space Center.

Table 1. List of Subprograms

(Note: The list of symbols appearing in columns labeled "Arguments," "Input," and "Output" are: P = pressure in atmospheres, D = density in moles per liter, T = temperature in Kelvin, S = entropy in Joules per mole Kelvin, C_p and C_v = specific heat capacity at constant pressure or volume in the same units of S, H = enthalpy in Joules per mole, W = velocity of sound in meters per second, λ = thermal conductivity and η = viscosity. Any deviations from the above will be noted in the text.

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
	PROGRAM FLUIDS - MAIN PROGRAM			
SUBROUTINE DATA CH4	Sets constants for Methane.	none	none	none
SUBROUTINE DATA N2	Sets constants for Nitrogen	none	none	
SUBROUTINE DATA O2	Sets constants for Oxygen	none	none	
SUBROUTINE DATA PH2 with entry points NH2, OH2, EH2 and FH2	Sets constants for Hydrogen	none	none	
SUBROUTINE PROPS	Main Property Routine of the 32 Term MBWR	P,D,T	D,T	P (a dummy variable
ENTRY POINTS				
PRESS	Calculates pressure	P,D,T	D,T	P = press

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
DPDD	Partial derivative of pressure with respect to density	P,D,T	D,T	$P = \left(\frac{\partial P}{\partial D}\right)$
DPDT	Partial derivative of pressure with respect to temperature	P,D,T	D,T	$P = \left(\frac{\partial P}{\partial T}\right)_{\rho}$
DSDN	One limit of the integral for entropy	P,D,T	D,T	$P = S_1$
DUDN	One limit of the integral for internal energy	P,D,T	D,T	$P = I_1$
TDSDT	One limit of the integral for specific heat capacity of constant volume	P,D,T	D,T	$P = C_v$
DP2D2	Second partial derivative of pressure with respect to density of a fluid	P,D,T	D,T	$P = \left(\frac{\partial^2 P}{\partial D^2}\right)_T$
FUNCTION VPN	Calculates the vapor pressure for a fluid input of pressure	T	T	P_{SAT}
FUNCTION FINDTV	Calculates the saturation temperature given a saturation pressure of a fluid	P	P	T_{SAT}
FUNCTION CV	Calculates the specific heat capacity of constant volume of a fluid	D,T	D,T	C_v
FUNCTION FINDD	Solves the equation of state for a density given pressure and temperature	P,T	P,T	D

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
SUBROUTINE REGULA	Regula-Falsi iteration, used when Newton's Iteration in FINDD fails	P,D,T	P,D,T	D
FUNCTION CP	Calculates specific heat capacity at constant volume of a fluid	D,T	D,T	C_p
FUNCTION DPDTVP	Calculates the derivative dP/dT of the vapor pressure curve of a fluid	T	T	$(dP/dT)_{SAT}$
FUNCTION FINDM	An alternative for D with a first guess for D as an input parameter	P,T,D	P,T,D	D
FUNCTION ENTROP	Calculates the entropy of a fluid	D,T	D,T	S
FUNCTION ENTHAL	Calculates the enthalpy of a fluid	D,T	D,T	H
FUNCTION SATL	Calculates the saturated liquid density of a fluid	T	T	D_{SATL}
ENTRY POINT SATV	Calculates the saturated vapor density of a fluid	T	T	D_{SATV}
FUNCTION SOUND	Calculates the velocity of sound of a fluid	D,T	D,T	W
FUNCTION VISC	Calculates the viscosity of a fluid	D,T	D,T	η $\mu g/cm\text{-}s$
FUNCTION THERM	Calculates the thermal conductivity of a fluid	D,T	D,T	λ mW/m-K
FUNCTION EXCESV	Calculates the "excess" viscosity of a fluid	D,g/cm^3,T	D,g/cm^3,T	$\Delta\eta$ $\mu g/cm\text{-}s$

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
ENTRY POINT EXCEST	Calculates the "excess" thermal conductivity of a fluid	D, g/cm^3, T	D, g/cm^3, T	$\Delta\lambda$ mW/m-K
FUNCTION FDCV	Calculates the first density correction for the viscosity of a fluid	D, g/cm^3, T	D, g/cm^3, T	$\Delta\eta$ $\mu g/cm\text{-}s$
ENTRY POINT FDCT	Calculates the first density correction for the thermal conductivity of a fluid	D, g/cm^3, T	D, g/cm^3, T	$\Delta\lambda$ mW/m-K x 10^{-2}
FUNCTION CRITC	Calculates the critical region enhancement for the thermal conductivity of a fluid	D, g/cm^3, T	D, g/cm^3, T	$\Delta\lambda$ mW/m-K
FUNCTION SENG	Equation of state for the critical region (used only by FUNCTION CRITC)	D, g/cm^3, T	D, g/cm^3, T	compressibility
FUNCTION DILV	Calculates the dilute gas	T	T	$\Delta\eta$ $\mu g/cm\text{-}s$
ENTRY DILT	Contribution of the viscosity and thermal conductivity of a fluid	T	T	$\Delta\lambda$ mW/m-K
FUNCTION CPI	Calculates ideal gas specific heat heat capacity at constant pressure of a fluid	T	T	C_p
ENTRY POINTS				
HI	Calculates ideal gas enthalpy of a fluid	T	T	H
SI	Calculates ideal gas entropy of a fluid	T	T	S

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION CPO	Calculates ideal gas specific heat capacity at constant pressure for hydrogen	T	T	C_p
FUNCTION CPOH	Calculates ideal gas enthalpy for hydrogen	T	T	H
FUNCTION CPOS	Calculates ideal gas entropy for hydrogen	T	T	S
FUNCTION ATKINT	Numerical x-y interpolation routine	X,YMAT,XMAT,N, NMAX,NES,ACRCY (see listing for explanation of arguments)	same	Y
SUBROUTINE REPRO	Used by Main Program to assemble properties for output			
SUBROUTINE LIMITS	Prints limits of equations of state when exceeded	P,T,IL	P,T,IL	PRINT
SUBROUTINE DATA NE	Assembles all neon properties for printout	none	none	all neon properties
SUBROUTINE DATA HE	Assembles all helium properties for printout	none	none	all He properties
SUBROUTINE INFO	Gives general information	none	none	information
SUBROUTINE H2INFO	Gives brief description of ORTHO-PARA states of hydrogen	none	none	information
SUBROUTINE SOURCE	Gives source of program	none	none	information

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION FNDDHE	Solves the helium equation of state for density	P,T	P,T	D
FUNCTION FNDPHE	Main properties subprogram for helium	D,T	D,T	P
ENTRY POINTS				
DPDTHE	Calculates $(\partial P/\partial T)_\rho$ for helium	D,T	D,T	$\left(\frac{\partial P}{\partial T}\right)$
DPDDHE	Calculates $(\partial P/\partial \rho)_T$ for helium	D,T	D,T	$\left(\frac{\partial P}{\partial \rho}\right)_T$
ENTRHE	Calculates entropy for helium	D,T	D,T	S
ENTHHE	Calculates enthalpy for helium	D,T	D,T	H
CVHE	Calculates specific heat capacity at constant volume for helium	D,T	D,T	C_v
FUNCTION SOUNHE	Calculates the velocity of sound for helium	D,T	D,T	W
FUNCTION VIRB	Calculates the second virial coefficient for helium	T	T	B
FUNCTION DBDT	Calculates the temperature derivative of the second virial for helium	T	T	B
FUNCTION D2DBDT	Calculates the second temperature derivative of the second virial for helium	T	T	B
FUNCTION VPNHE	Calculates the vapor pressure of helium	T	T	P
FUNCTION CPHE	Calculates specific heat capacity at constant pressure for helium	T	T	C_p

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION DELT	Calculates a correction to the 1968 helium temperature scale	T	T	ΔT
FUNCTION VPTEHE	Solves the vapor pressure equation for temperature for helium	P	P	T
FUNCTION DVPNHE	Calculates dP/dT of the vapor pressure for helium	T	T	$\left(\frac{\partial P}{\partial T}\right)_\rho$
FUNCTION TRANSP	Calculates thermal conductivity and viscosity of helium	D,T	T	
ENTRY POINTS				
THREHE	Calculates the thermal conductivity for helium	D,T	T	d $\frac{mW}{cm\ K}$
VISCHE	Calculates viscosity for helium	D,T	T	η micropoise
FUNCTION VISCX	Calculates the dilute gas viscosity of helium from 100 K to 300 K	T	T	η micropoise
FUNCTION DELC	Calculates excess thermal conductivity for helium	D,T	D,T	λ $\frac{mW}{cm\ K}$
FUNCTION CONZ	Used with DELC	T	T	
FUNCTION VISCDT	Calculates viscosity of helium for temperatures below 300 K	D,T	D,T	η micropoise

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION CRITIC	Calculates critical enhancement of thermal conductivity for helium	D, gm/cm^3, T	D,T	$\lambda\ \frac{mW}{cm\ s}$
FUNCTION DSATV	Calculates density of saturated liquid and gaseous helium	T	T	D, g/cm^3
ENTRY POINTS				
DSATV	gas	T	T	D, g/cm^3
DSATL	liquid	T	T	D, g/cm^3
FUNCTION PMELT	Calculates a melting pressure for helium	T	T	P
FUNCTION FNDPNE	Redefinition of the pressure function	D,T	D,T	P
FUNCTION ENTHA	Calculates enthalpy for neon	P	P,D,T	H
FUNCTION DLIQNE	Calculates the density of saturated liquid neon	T	T	D
FUNCTION DPDDNE	Calculates $\left(\frac{\partial P}{\partial T}\right)_T$ for neon	DT	D,T	$\left(\frac{\partial P}{\partial D}\right)_T$
FUNCTION ENTR	Calculates the entropy of neon - liquid phase, i.e., $T < T_c$ and $P > P_{sat}$	D,T	D,T	$S\ \frac{\text{liter atm}}{\text{mol-K}}$
SUBROUTINE DATN	Sets the constants for the neon equation of state	none	none	A1 thru A14
FUNCTION PC	Calculates the pressure for neon	D,T	D,T	P
FUNCTION FNDTNE	Solves the neon equation of state for temperature	P,D	P,D	T

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION FINDP	Checks the pressure of various fluids	D,T	D,T	P
FUNCTION DPDTNE	Calculates $\left(\frac{\partial P}{\partial T}\right)_\rho$ for neon	D,T	D,T	$\left(\frac{\partial P}{\partial T}\right)_\rho$
FUNCTION FNDTHE	Solves the helium equation of state for temperature	P,D	P,D	T
FUNCTION FINDT	Solves the 32 term BWR equation of state for temperature	P,D	P,D	T
FUNCTION CPOSNE	Calculates the ideal gas entropy for neon	T	T	S
FUNCTION CPOHNE	Calculates the ideal gas enthalpy for neon	T	T	H
FUNCTION FNDDNE	Solves the neon equation of state for density	P,T	P,T	D
FUNCTION ENTH	Calculates enthalpy for neon - liquid region, i.e., $T < T_c$, $P > P_{sat}$	P,D,T	P,D,T	H
FUNCTION VPTENE	Solves to vapor-pressure of neon for temperature	P	P	T
FUNCTION ENTHNE	Calculates enthalpy for neon - gaseous phase	P,D,T	P,D,T	H
FUNCTION ENTRNE	Calculate entropy for neon in the gaseous phase	D,T	D,T	S

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION VPNNE	Calculates the saturated vapor pressure of neon	T	T	P
FUNCTION DVPNNE	Calculates $\left(\frac{\partial P}{\partial T}\right)_{sat}$ for neon	T	T	$\left(\frac{dP}{dT}\right)_{sat}$

5. Properties of Hydrogen

The thermodynamic properties of hydrogen are calculated from a 32 term empirical equation of state. The source of the equation of state is NBSIR 75-814 (Roder and McCarty, 1975). The program allows the option of ortho, para, and normal hydrogen modifications. The properties for normal and ortho hydrogen are obtained by changing the ideal gas thermodynamic properties from parahydrogen to ortho or normal hydrogen. This changes the derived thermodynamic properties but does nothing to the PVT surface. Therefore the PVT for all of the hydrogen options are the same.

Table 2. Properties and Associated Estimated Uncertainties for Hydrogen

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.25	0.20
density	0.1	0.25	0.2
temperature	0.1	0.25	0.2
enthalpy	1 J/mol	3 J/mol	5.10 J/mol
entropy	1.0	1.0	1
C_p	3.0	2.0	3.0
C_v	3.0	2.0	3.0
speed of sound	2.0	1.0	1.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 3. Pressure and Temperature Range for Hydrogen

Temperature range	13.8 to 400 K
	-434.83 to 260.43°F
Pressure range	0** to 1200 bar
	0 to 17404.5 psia
<u>Fixed Points</u>	
Triple Point Temperature	13.8 K*
	-434.83°F
Triple Point Pressure	0.07043101 bar**
	1.0215154 psia
Triple Point Density-Vapor	0.0632229 moles/liter
	0.007956667 lb/cu ft
Liquid	38.21429 moles/liter
	4.809273 lb/cu ft
Critical Point Temperature	32.938 K*
	-459.67°F
Critical Point Pressure	12.83768 bar
	186.19481 psia
Critical Point Density	15.556 moles/liter*
	1.95774 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 4. Properties for Computer Program Performance Test for Hydrogen

	Density	Temp	H	S	C_p	C_v	Sound Velocity
	mol/L	K	J/mol	J/mol-K	J/mol-K		m/s
			Saturated Vapor at 1.01325 bar				
para	.6644446	20.27686	381.4283	60.38879	24.67806	13.31149	354.0753
normal	.6644446	20.27686	1444.122	78.76558	24.67806	13.31149	354.0753
ortho	.6644446	20.27686	1798.340	78.65680	24.67806	13.31149	354.0753
			Saturated Liquid at 1.01325 bar				
para	35.11883	20.27686	-516.5543	16.10387	19.48814	11.42787	1100.731
normal	35.11883	20.27686	546.1399	34.48066	19.48814	11.42787	1100.731
ortho	35.11883	20.27686	900.3573	34.37187	19.48814	11.42787	1100.731
			Single Phase at 300 K and 1000 bar				
para	24.42809		9842.094	72.63775	31.56691	22.95644	2138.057
normal	24.42809		9897.657	84.32367	30.48744	21.87697	2152.397
ortho	24.42809		9916.192	81.98481	30.12762	21.51714	2157.474

6. Properties of Helium

The thermodynamic properties of helium are calculated from a 32 term modified Benedict-Webb-Rubin equation of state. The source of the equation of state is a paper by McCarty (1973). The transport properties for helium are from NBS Technical Note 631 (McCarty, 1972). Tabular values of the thermodynamic and transport properties of helium are given in Technical Note 631 and are identical to those produced by this computer program.

Table 5. Properties and Associated Estimated Uncertainties for Helium

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	10.0	0.2	0.2
density	0.5	0.2	0.2
temperature	.5	0.2	0.2
enthalpy	2.0	1.0	1.0
entropy	2.0	1.0	1.0
C_p	2.0	2.0	.5
C_v	2.0	1.5	.5
speed of sound	2.0	1.0	.5
thermal conductivity	10.0	10.0	10.0
viscosity	8.0	8.0	10.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 6. Pressure and Temperature Range for Helium

Temperature range	2 to 1500 K
	-456.07 to 2240.33°F
Pressure range	0** to 1000 bar
	0 to 14504. psia
<u>Fixed Points</u>	
Lambda Temperature	2.1720 K*
	-455.760°F
Lambda Pressure	.04963285 bar**
	.71986364 psia
Lambda Density-Vapor	.2904484 moles/liter
	.72575547 lb/cu ft
Liquid	36.53426 moles/liter
	9.1289672 lb/cu ft
Critical Point Temperature	5.2014 K*
	-450.307°F
Critical Point Pressure	2.274640 bar
	32.990864 psia
Critical Point Density	17.3987 moles/liter*
	4.347485 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program, the program does not reproduce this number exactly.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 7. Properties for Computer Program Performance Test for Helium

Density	Temp	H	S	C_p	C_v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K		m/s	mW/m-K	μg/cm-s
				Saturated Vapor at 1.01325 bar				
4.219020	4.224449	120.5928	33.16956	39.12776	13.40124	100.1654	10.62098	12.46551
				Saturated Liquid at 1.01325 bar				
31.22392	4.224449	38.86948	13.82407	19.93710	9.477176	171.9782	19.63999	31.69095
				Single Phase at 300 K and 1000 bar				
28.07788		7544.967	68.82269	20.89332	13.63682	1366.437	201.1403	222.7074

7. Properties of Neon

The thermodynamic properties of neon are calculated from an 18 term empirical equation of state by McCarty and Stewart (1965). No specific heat capacities are calculated for neon because the accuracy of the model of the equation of state does not warrant the calculation. Transport properties for neon are not available in the form of a mathematical model as is the case for some of the other fluids.

Table 8. Properties and Associated Estimated Uncertainties for Neon

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	10.0	0.5	0.5
density	2.0	1.0	1.0
temperature	2.0	1.0	1.0
enthalpy	20.0	1.0	10.0
entropy	20.0	1.0	10.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 9. Pressure and Temperature Range for Neon

Temperature range	25 to 300 K
	-414.67 to 80.33°F
Pressure range	.1** to 200 bar
	1.450 to 2901. psia
Fixed Points	
Triple Point Temperature	25 K*
	-414.67°F
Triple Point Pressure	.5102339 bar**
	7.4003172 psia
Triple Point Density-Vapor	.2528246 moles/liter
	.31855482 lb/cu ft
Liquid	61.45071 moles/liter
	77.42688 lb/cu ft
Critical Point Temperature	44.40 K*
	-379.75°F
Critical Point Pressure	26.57086 bar
	385.37775 psia
Critical Point Density	23.93 moles/liter*
	30.151 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 10. Properties for Computer Program Performance Test for Neon

Density	Temp	H	S	C_p	C_v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K		m/s	mW/m-K	μg/cm-s
			Saturated Vapor at 1.01325 bar					
.4734012	27.09186	1838.933	68.00152	-	-	-	-	-
			Saturated Liquid at 1.01325 bar					
59.69732	27.09186	101.6894	3.875716	-	-	-	-	-
			Single Phase at 300 K and 200 bar					
7.339088		7648.066	74.11069	-	-	-	-	-

8. Properties of Nitrogen

The thermodynamic properties are calculated from a 32 term modified equation of state taken from Jacobsen, et al. (1973). The same functional form of the equation of state used for nitrogen has also been used here for hydrogen, oxygen, argon and methane. The transport properties are from Hanley, et al. (1974).

Table 11. Properties and Associated Estimated Uncertainties for Nitrogen

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.3	0.3
density	0.5	0.3	0.2
temperature	0.5	0.3	0.2
enthalpy	3.0	1.0	1.0
entropy	2.0	1.0	1.0
C_p	5.0	5.0	5.0
C_v	5.0	5.0	5.0
speed of sound	2.0	0.25	1.0
thermal conductivity	4.0	4.0	6.0
viscosity	2.0	2.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 12. Pressure and Temperature Range for Nitrogen

Temperature range	63.15 to 1900 K
	346 to 2960.33°F
Pressure range	0** to 1000 bar
	0 to 145040. psia
<u>Fixed Points</u>	
Triple Point Temperature	63.15 K*
	346 °F
Triple Point Pressure	.1246399 bar**
	1.807749 psia
Triple Point Density-Vapor	.2396164 moles/liter
	.04190847 lb/cu ft
Liquid	30.97717 moles/liter
	54.178504 lb/cu ft
Critical Point Temperature	126.26 K*
	-232.402°F
Critical Point Pressure	34.10034 bar
	484.5836 psia
Critical Point Density	11.21 moles/liter*
	19.606 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 13. Properties for Computer Program Performance Test for Nitrogen

Density	Temp	H	S	C_p	C_v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K		m/s	mW/m-K	μg/cm-s
				<u>Saturated Vapor at 1.01325 bar</u>				
.1646146	77.36267	2163.506	151.447	31.95042	21.58560	174.8439	7.569252	52.81762
				<u>Saturated Liquid at 1.01325 bar</u>				
28.86246	77.36267	-3400.812	79.53773	57.79680	27.82053	938.8844	133.6724	1515.714
				<u>Single Phase at 300 K and 1000 bar</u>				
23.93016		8447.358	128.3785	37.85003	23.93016	840.4759	85.35870	523.9142

9. Properties of Oxygen

The thermodynamic properties of oxygen are calculated from a 32 term empirical equation of state given in NBSIR 78-882 by Weber (1978). The functional form of the oxygen equation of state is the same as was used for hydrogen, nitrogen, oxygen and methane. The transport properties are from Hanley et al. (1974).

Table 14. Properties and Associated Estimated Uncertainties for Oxygen

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.25	0.15
density	0.1	0.25	0.15
temperature	0.1	0.2	0.1
enthalpy	0.5	0.25	0.5
entropy	0.5	0.25	0.5
C_p	3.0	5.0	3.0
C_v	3.0	5.0	3.0
speed of sound	2.0	0.5	0.5
thermal conductivity	4.0	4.0	6.0
viscosity	2.0	2.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 15. Pressure and Temperature Range for Oxygen

Temperature range	54.359 to 400 K
	-361.8238 to 260.33°F
Pressure range	0** to 1200 bar
	0 to 17404. psia
Fixed Points	
Triple Point Temperature	54.359 K*
	-361.8238°F
Triple Point Pressure	.001490085 bar**
	.021611856 psia
Triple Point Density-Vapor	.0003275488 moles/liter
	6.5431796×10^{-4} lb/cu ft
Liquid	40.81997 moles/liter
	81.542780 lb/cu ft
Critical Point Temperature	154.481 K*
	-181.4242°F
Critical Point Pressure	50.42218 bar
	731.31190 psia
Critical Point Density	13.63 moles/liter*
	27.228 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 16. Properties for Computer Program Performance Test for Oxygen

Density	Temp	H	S	C_p	C_v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K	J/mol-K	m/s	mW/m-K	μg/cm-s
				Saturated Vapor at 1.01325 bar				
.1399257	90.19135	2537.538	169.5844	31.34338	21.71976	177.4626	8.460045	66.97377
				Saturated Liquid at 1.01325 bar				
35.65789	90.19135	-4260.782	94.19495	54.22163	29.53503	905.4406	71.85019	716.0933
				Single Phase at 300 K and 1000 bar				
24.42347		6930.248	140.4206	40.44384	24.67886	732.8926	66.50174	597.4560

10. Properties of Argon

The thermodynamic properties of argon have been calculated from a 32 term empirical equation of state from Hanley, et al. (1974). The functional form of the argon equation of state is the same as was used for hydrogen, nitrogen, oxygen and methane. The transport properties for argon were also taken from Hanley, et al. (1974).

Table 17. Properties and Associated Estimated Uncertainties for Argon

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	10.0	0.3	0.3
density	0.25	0.3	0.3
temperature	0.25	0.3	0.3
enthalpy	2.0	1.0	1.5
entropy	1.0	1.0	1.0
C_p	5.0	5.0	5.0
C_v	5.0	5.0	5.0
speed of sound	5.0	5.0	5.0
thermal conductivity	4.0	4.0	6.0
viscosity	2.0	2.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 18. Pressure and Temperature Range for Argon

Temperature range	83.80 to 400 K
	-308.83 to 260.33°F
Pressure range	0** to 1000 bar
	0 to 14504. psia
Fixed Points	
Triple Point Temperature	83.80 K*
	-308.83°F
Triple Point Pressure	.6890708 bar**
	9.9941271 psia
Triple Point Density-Vapor	.1015395 moles/liter
	.25322653 lb/cu ft
Liquid	35.40018 moles/liter
	88.283522 lb/cu ft
Critical Point Temperature	150.86 K*
	-188.122°F
Critical Point Pressure	48.98050 bar
	710.40210 psia
Critical Point Density	13.41 moles/liter*
	33.443 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 19. Properties for Computer Program Performance Test for Argon

Density	Temp	H	S	C_p	C_v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K		m/s	mW/m-K	μg/cm-s
Saturated Vapor at 1.01325 bar								
.1445217	87.28153	9425.279	128.5414	23.29635	13.59023	170.3420	5.856927	72.51142
Saturated Liquid at 1.01325 bar								
34.87034	87.28153	2952.449	53.37806	51.00242	34.11186	608.5500	128.0897	2594.300
Single Phase at 300 K and 1000 bar								
24.07985		12354.77	90.55855	31.30528	15.70327	716.8781	72.17791	750.1518

11. Properties of Methane

The thermodynamic properties of methane are calculated from a 32 term empirical equation of state by McCarty (1974). The functional form of the methane equation of state is the same as was used for hydrogen, nitrogen, oxygen, and argon. The transport properties are from Hanley, et al. (1977).

Table 20. Properties and Associated Estimated Uncertainties for Methane

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.25	0.25
density	0.1	0.25	0.25
temperature	0.1	0.25	0.25
enthalpy	1.0	0.5	0.5
entropy	0.5	0.5	0.5
C_p	2.0	5.0	2.0
C_v	2.0	5.0	2.0
speed of sound	1.0	0.3	0.3
thermal conductivity	5.0	5.0	4.0
viscosity	3.0	3.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 21. Pressure and Temperature Range for Methane

Temperature range	90.68 to 500 K
	-296.446 to 440.33°F
Pressure range	0** to 350 bar
	0 to 5076. psia
Fixed Points	
Triple Point Temperature	90.68 K*
	-296.446°F
Triple Point Pressure	.1174350 bar**
	1.7032507 psia
Triple Point Density-Vapor	.01569094 moles/liter
	.015713995 lb/cu ft
Liquid	28.15114 moles/liter
	28.192503 lb/cu ft
Critical Point Temperature	190.555 K*
	-116.671°F
Critical Point Pressure	45.98838 bar
	667.00507 psia
Critical Point Density	10.23 moles/liter*
	10.245 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 22. Properties for Computer Program Performance Test for Methane

Density	Temp	H	S	C_p	C_v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K		m/s	mW/m-K	μg/cm-s
			Saturated Vapor at 1.01325 bar					
.1131362	111.6319	12781.80	152.5707	35.28294	25.73168	271.5553	13.21587	44.74053
			Saturated Liquid at 1.01325 bar					
26.34296	111.6319	4588.008	79.17229	55.81038	32.76708	1351.590	186.0727	1178.028
			Single Phase at 300 K and 350 bar					
14.36660		15715.38	128.9694	55.42562	31.19452	704.7618	81.50882	272.0201

12. References

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[9] Hanley, H. J. M., Haynes, W. M. and McCarty, R. D., The Viscosity and Thermal Conductivity Coefficients for Dense Gaseous and Liquid Methane, J. Phys. Chem. Ref. Data 6, No. 2, 597-609 (1977).

Appendix 1

Example of the Use of the Program

```
CALL,TPROPS
 HI, WELCOME TO THE WORLD OF FLUID PROPERTIES, IF YOU ARE NOT FAMILIAR WITH THE
 PROGRAM PLEASE ENTER A 0
? 0
 WHEN THE PROGRAM ASKS FOR A FLUID SELECTION, ENTER THE APPROPRIATE NUMBER
 AN INAPPROPRIATE NUMBER WILL TERMINATE THE PROGRAM
  WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY, AND
  TEMPERATURE, ENTER ANY 2 OF THE THREE AND A 0 FOR THE THIRD.
  THE ORDER MUST BE P, D,T, AND ONE OF THE THREE MUST BE 0.
 IF ALL THREE ARE 0 THE PROGRAM ASKS FOR A NEW FLUID
 IF YOU ARE INTERESTED IN A DEFINITION OF THE VARIOUS
 MODIFICATIONS OF HYDROGEN ENTER A 1, IF NOT ENTER A 0
? 0
 IF YOU ARE INTERESTED IN THE SOURCES OF THESE PROGRAMS
 ENTER A 1 IF NOT ENTER A 0,
? 0
  SELECT A FLUID FROM THE FOLLOWING LIST
    PARA HYDROGEN=1
    NORMAL HYDROGEN=10
    ORTHO HYDROGEN=11
    HELIUM=2
    NEON=3
    NITROGEN=4
    OXYGEN=5
    ARGON=6
    METHANE=7
                                            TERMINATION=8
? 4
 THE RANGE OF TEMPERATURE FOR NITROGEN IS 63.15 TO 1900K
 WITH PRESSURES TO 10000 BAR
 DO YOU PREFER ENGINEERING UNITS OR METRIC UNITS ?
 ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC
? 1
 DO YOU WANT SATURATION PROPERTIES ?
 ENTER 0 FOR YES OR 1 FOR NO
? 1
 DO YOU WANT A SINGLE POINT OR A TABLE OF PROPERTIES ?
 ENTER A 0 FOR A SINGLE POINT OR A 1 FOR A TABLE
? 1
 ENTER A PRESSURE, A STARTING TEMPERATURE, A FINAL
 TEMPERATURE AND A TEMPERATURE INCREMENT, IN BARS, DEGREES
 K, AND IN THAT ORDER
? 10,100,200,10
 PRESSURE  DENSITY   TEMP       H        S       CP      CV    S SOUND   COND    VISC
   BAR      MOL/L     K       J/MOL   J/MOL-K    J/MOL-K      M/S     MW/M-K MI F ^M-S
   10.00 24.6342   100.00 -2032.40   94.64   64.36   26.23   616.75   98.53   731.3
   10.00  1.3169   110.00  2731.63  140.55   40.17   23.18   194.20   12.77    79.7
   10.00  1.1452   120.00  3111.38  143.85   36.25   22.33   208.92   13.35    85.5
   10.00  1.0226   130.00  3462.67  146.67   34.19   21.85   221.53   14.02    91.5
   10.00   .9282   140.00  3797.88  149.15   32.94   21.56   232.83   14.73    97.5
   10.00   .8523   150.00  4122.94  151.39   32.12   21.36   243.20   15.47   103.4
   10.00   .7894   160.00  4441.10  153.45   31.55   21.23   252.87   16.23   109.2
   10.00   .7360   170.00  4754.35  155.35   31.13   21.14   261.98   17.00   114.9
   10.00   .6901   180.00  5063.95  157.12   30.81   21.07   270.64   17.76   120.6
   10.00   .6499   190.00  5370.75  158.78   30.56   21.02   278.93   18.53   126.1
   10.00   .6145   200.00  5675.36  160.34   30.37   20.98   286.88   19.29   131.5
 ENTER A PRESSURE, A STARTING TEMPERATURE, A FINAL
 TEMPERATURE AND A TEMPERATURE INCREMENT, IN BARS, DEGREES
 K, AND IN THAT ORDER
? 0,0,0,0
```

```
   SELECT A FLUID FROM THE FOLLOWING LIST
     PARA HYDROGEN=1
     NORMAL HYDROGEN=10
     ORTHO HYDROGEN=11
     HELIUM=2
     NEON=3
     NITROGEN=4
     OXYGEN=5
     ARGON=6
     METHANE=7
                                   TERMINATION=8
? 8
EXIT.
```

Appendix 2

Program Listings

```
      PROGRAM FLUIDS(INPUT=180,OUTPUT)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON /CONT/IF
      COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
  100 FORMAT(* HI, WELCOME TO THE WORLD OF FLUID PROPERTIES, IF YOU ARE NOT
     1NOT FAMILIAR WITH THE PROGRAM PLEASE ENTER A 0 *)
      PRINT 100
      READ 101,I
      IF(I.EQ.0)CALL INFO
  101 FORMAT(I1)
   99 PRINT 102
      PRINT 104
  102 FORMAT(*  SELECT A FLUID FROM THE FOLLOWING LIST*)
  104 FORMAT(*     PARA HYDROGEN=1*/*     NORMAL HYDROGEN=10*/*     ORTHO H
     1YDROGEN=11*/*     HELIUM=2*/*     NEON=3*/*     NITROGEN=4*/*     OXYG
     2EN=5*/*     ARGON=6*/*     METHANE=7*/*
     4     TERMINATION=8*)
      READ *,IF
      GO TO(1,2,3,4,5,6,7,999,999,10,11),IF
    1 CALL DATA PH2
      GO TO 13
    2 CALL DATA HE
      GO TO 99
    3 CALL DATA NE
      GO TO 99
    4 CALL DATA N2
      GO TO 13
    5 CALL DATA O2
      GO TO13
    6 CALL DATA AR
      GO TO 13
    7 CALL DATA CH4
      GO TO 13
   10 CALL  NH2
      GO TO 13
   11 CALL  OH2
      GO TO 13
   13 PRINT 105
  105 FORMAT(* DO YOU PREFER ENGINEERING UNITS OR METRIC UNITS ?*
     1/* ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC*)
      READ 101,IU
      PRINT 106
  106 FORMAT(* DO YOU WANT SATURATION PROPERTIES ?*
     1/* ENTER 0 FOR YES OR 1 FOR NO*)
      READ 101,IC
      PRINT 107
  107 FORMAT(* DO YOU WANT A SINGLE POINT OR A TABLE OF PROPERTIES ?*
     1/* ENTER A 0 FOR A SINGLE POINT OR A 1 FOR A TABLE*)
      READ 101,IV
   21 IF(IC.EQ.0)GO TO 30
      IF(IV.EQ.1)GO TO 40
   22 IF(IU.EQ.0)GO TO 19
      PRINT 103
      READ *,P,D,T
      P=P/1.01325
      GO TO 20
   19 PRINT 108
  108 FORMAT(* ENTER PRESSURE IN LB/SQ IN, DENSITY IN LB/CU FT, AND*
     1/* TEMPERATURE IN DEGREES F*)
      READ *,P,D,T
      P=P/14.695949
      D=D*16.01846371/EM
```

```
      IF(T.EQ.0.0)GO TO 20
      T=(T-32.)/1.8+273.15
   20 IF(P.LE.0.0)GO TO 14
  103 FORMAT(* ENTER PRESSURE IN BAR, DENSITY IN MOLES/LITER, AND TEMPER
     1ATURE IN KELVINS*)
      IF(D.LE.0.0)GO TO 17
      IF(T.LE.0.0)GO TO 12
      GO TO 22
   12 IF(P.LE.0.OR.D.LE.0.0)GO TO 99
      T=FIND T(P,D)
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 22
      GO TO 16
   17 IF(T.LE.0.OR.P.LE.0)GO TO 99
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 22
      D=FIND D(P,T)
      GO TO 16
   14 IF(D.LE.0.0.OR.T.LE.0)GO TO 99
      P=FIND P(D,T)
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 22
   16 CALL REPRO(P,D,T,IU,IV,IC,IP,TF,DELT)
      GO TO 22
   30 PRINT 109
  109 FORMAT(* DO YOU WANT SATURATED LIQUID OR SATURATED VAPOR*
     1/* ENTER A 0 FOR LIQUID OR 1 FOR VAPOR*)
      READ 101,IP
      IF(IV.EQ.1)GO TO 40
      PRINT 111
  111 FORMAT(* DO YOU WANT TO ENTER WITH TEMPERATURE OR PRESSURE *
     1/* ENTER 0 FOR TEMPERATURE OR 1 FOR PRESSURE*)
      READ 101,II
      IF(II.EQ.1)GO TO 35
  211 IF(IU.EQ.1)GO TO 31
  112 FORMAT(* ENTER A TEMPERATURE IN DEGREES F*)
      PRINT 112
      READ *,TI
      T=(TI-32.)/1.8+273.15
      IF(T.LE.0.0)GO TO 99
      GO TO 33
   31 PRINT 113
  113 FORMAT(* ENTER A TEMPERATURE IN DEGREES K*)
      READ *,T
   33 IF(T.LE.0.0)GO TO 99
      IF(T.GT.TCC.OR.T.LT.TTP)GO TO 34
      P=VPN(T)
      IF(IP.EQ.0)P=P+.00001
      D=FIND D(P,T)
      CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
      GO TO 211
   34 PRINT 114,TCC, TTP
  114 FORMAT(* YOUR INPUT TEMPERATURE IS OUTSIDE THE RANGE OF THE*
     1/* SATURATION TEMPERATURES FOR THIS FLUID.*
     2/* TC=*,F6.2,* TTP=*,F6.2,* TRY AGAIN*)
      GO TO 211
   35 IF(IU.EQ.1)GO TO 36
      PRINT 115
  115 FORMAT(* ENTER A PRESSURE IN LB/SQ IN*)
      READ *,PI
      IF(PI.LE.0.0)GO TO 99
      P=PI/14.695949
      GO TO 37
```

```
 36 PRINT 116
116 FORMAT(* ENTER A PRESSURE IN BAR*)
    READ *,PI
    IF(PI.LE.0.0)GO TO 99
    P=PI/1.01325
 37 IF(P.GT.PCC.OR.P.LT.PTP)GO TO 38
    T=FIND TV(P)
    P=VPN(T)
    IF(IP.EQ.0)P=P+.0001
    D=FIND D(P,T)
    CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
    GO TO 35
 38 PRINT 117,PCC,PTP
117 FORMAT(* YOUR INPUT PRESSURE IS OUTSIDE THE RANGE OF SATURATION*
   1/* PRESSURES FOR THIS FLUID.*
   2/* PC=*,F6.3,* PTP=*,F6.5,* TRY AGAIN*)
    GO TO 35
 40 IF(IC.EQ.1)GO TO 50
    IF(IU.EQ.1)GO TO 41
    PRINT 118
118 FORMAT(*  ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE*
   1/* AND A TEMPERATURE INCREMENT, IN DEGREES F AND IN THAT ORDER*)
    READ *,TS,TF,DELT
    IF(DELT.LE.0.0)GO TO 99
    TS=(TS-32.)/1.8+273.15
    TF=(TF-32.)/1.8+273.15
    DELT=DELT/1.8
    IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 45
    IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 45
    GO TO 42
 41 PRINT 119
119 FORMAT(* ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE*
   1/* AND A TEMPERATURE INCREMENT IN KELVINS AND IN THAT ORDER*)
    READ *,TS,TF,DELT
    IF(DELT.LE.0.0)GO TO 99
    IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 45
    IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 45
 42 T=TS
    P=VPN(T)
    IF(IP.EQ.0.0)P=P+.0001
    D=FIND D(P,T)
    CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
    GO TO 40
 45 PRINT 120,TCC,TTP
120 FORMAT(* EITHER YOUR STARTING OR FINAL TEMPERATURE IS OUTSIDE*
   L/* THE RANGE OF SATURATION TEMPERATURES.*
   2/* TC=*,F6.2,* TTP=*,F6.2,* TRY AGAIN*)
    GO TO 40
 50 IF(IU.EQ.1)GO TO 51
    PRINT 121
121 FORMAT(* ENTER PRESSURE, STARTING TEMPERATURE, FINAL TEMPERATURE*
   1/* AND A TEMPERATURE INCREMENT, IN LB/CU FT, DEGREES F, AND IN*
   2/* THE ABOVE ORDER*)
    READ *,PI,TS,TF,DELT
    IF(DELT.LE.0.0)GO TO 99
    P=PI/14.695949
    T=(TS-32.)/1.8+273.15
    TF=(TF-32.)/1.8+273.15
    DELT=DELT/1.8
    CALL LIMITS(P,T,IL)
    IF(IL.LE.0)GO TO 50
    CALL LIMITS(P,TF,IL)
    IF(IL.LE.0)GO TO 50
```

```
      GO TO 52
   51 PRINT 122
  122 FORMAT(* ENTER A PRESSURE, A STARTING TEMPERATURE, A FINAL*
     1/* TEMPERATURE AND A TEMPERATURE INCREMENT, IN BARS, DEGREES*
     2/* K, AND IN THAT ORDER*)
      READ *,PI,TS,TF,DELT
      IF(DELT.LE.0.0)GO TO 99
      T=TS
      P=PI/1.01325
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 50
      CALL LIMITS(P,TF,IL)
      IF(IL.LE.0)GO TO 50
   52 D=FIND D(P,T)
      CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
      GO TO 50
  999 CONTINUE
      STOP
      END
      SUBROUTINE DATA ET
      PRINT 100
  100 FORMAT(* ETHANE IS SCHEDULED TO BE ADDED TO THE FLUIDS*
     1/* PACK IN THE NEXT FISCAL YEAR*)
      RETURN
      ENTRY DATA PR
      PRINT 101
  101 FORMAT(* PROPANE IS SCHEDULED TO BE ADDED TO THE FLUIDS*
     1/* PACK AFTER FY78*)
      RETURN
      ENTRY DATA NH3
      PRINT 102
  102 FORMAT(* AMMONIA IS SCHEDULED TO BE ADDED TO THE FLUIDS*
     1/* PACK DURING FY78*)
      RETURN
      ENTRY DATA SH
      ENTRY DATA SO
      PRINT 103
  103 FORMAT(* THE SLUSH PROGRAMS WILL BE ADDED TO THE FLUIDS*
     1/* PACK IN FY78*)
      RETURN
      END
      SUBROUTINE RE PRO(P,D,T,IU,IV,IQ,IP,TF,DELT)
       DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL
      COMMON/CONT/IC
      COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
      N=500
      IF(IV.EQ.0)TF=T-1.
      PRINT 100
      IF(IU.EQ.0)GO TO 1
      PRINT 102
      GO TO 2
    1 PRINT 103
      PRINT 104
    2 CONTINUE
      DO 10 I=1,N
      IF(I.EQ.1)GO TO 3
      D=FIND D(P,T)
    3 H=ENTHAL(PV
       S=ENTROP(D,T)
      W=SOUND(D,T)
      CPP=CP(D,T)
      CVV=CV(D,T)
```

```
      Q=P*1.01325
      IF(IU.EQ.0)GO TO 21
      IF(IC.EQ.1.OR.IC.EQ.10.OR.IC.EQ.11)GO TO 20
      IF(IC.EQ.9)GO TO 20
      TH=THERM(D,T)
      V=VISC(D,T)
      PRINT 101,Q,D,T,H,S,CPP,CVV,W,TH,V
      GO TO 9
   20 PRINT 101,Q,D,T,H,S,CPP,CVV,W
      GO TO 9
  101 FORMAT(F8.2,F8.4,F9.2,F9.2,F8.2,2F7.2,F8.2,F7.2,F7.1)
  100 FORMAT(* PRESSURE  DENSITY   TEMP       H         S      CP      CV   S
     1 SOUND   COND   VISC*)
  102 FORMAT(*   BAR      MOL/L       K       J/MOL  J/MOL-K     J/MOL-K
     1M/S     MW/M-K MIG/CM-S*)
  103 FORMAT(*  LB/SQ IN LB/CU FT  DEG F   BTU/LB        BTU/LB-F
     1 F/S     BTU   LB/FT-S*)
  104 FORMAT(*
     1       FT-HR-F  E+7*)
   21 H=H/(2.324445*EM)
      S=S/(4.184001*EM)
      CPP=CPP/(4.184001*EM)
      CVV=CVV/(4.184001*EM)
      W=W*3.280840
      PO=P*14.695949
      DO=D*EM/16.01846371
      TO=T*1.8-459.67
      IF(IC.EQ.1.OR.IC.GT.8)GO TO 22
      TH=THERM(D,T)*.000578176
      V=VISC(D,T)*.0067196897
      PRINT 105,PO,DO,TO,H,S,CPP,CVV,W,TH,V
  105 FORMAT(F8.1,F8.3,2F9.2,F8.2,2F7.3,F8.0,F7.4,F7.3)
      GO TO 9
   22 PRINT 101,PO,DO,TO,H,S,CPP,CVV,W
    9 T=T+DELT
      IF(T.GT.TF+.01)GO TO 11
      IF(IQ.EQ.0)P=VPN(T)
      IF(IP.EQ.0)P=P+.0001
   10 CONTINUE
   11 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DATA CH4
      DIMENSION G(32),VP(9),GI(11)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      DIMENSION A(20)
      COMMON/SEN/BETA,XO,DELTA,E1, E2, AGAM
      COMMON/CPID/GI
      COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/ISP/N,NW,NWW
      COMMON/SATC/A,DTPV
      NWW=0
      PRINT 100
  100 FORMAT(* THE RANGE OF TEMPERATURE FOR METHANE IS 90.68 TO 500 K*
     1/* WITH PRESSURES TO 350 BAR*)
     N=0 $ NW=0
      EM=16.042 $ EOK=168. $ RM=4.101E-08 $ TC=190.555
      DC=0.1627 $ X=1.7124 $ PC=45.95 $ SIG=3.68
      XO=0.164 $ BETA=0.355 $ DELTA=4.352 $ E1=2.03 $ E2=0.287
      AGAM=1.190
C     PARAMETERS FOR TRANSPORT
C     PROPERTIES - HANLEY ET. AL. JOURNAL
C     OF PHY. CHEM. REF. DATA VOL 6 NO 2
C     1977
C DATA SUBROUTINE FOR METHANE
      GV(1)=-2.0909747942E+2
      GV(2)=2.6472692181E+2
      GV(3)=-1.4728175613E+2
      GV(4)=4.7167401921E+1
      GV(5)=-9.4918721789E+0
      GV(6)=1.2199792872E+0
      GV(7)=-9.62799355746E-2
      GV(8)=4.2741516570E-3
      GV(9)=-8.1415307247E-05
      GT(1)=-2.1476213125E+5
      GT(2)=2.1904610575E+5
      GT(3)=-8.6180973719E+4
      GT(4)=1.4960986936E+4
      GT(5)=-4.7306603177E+2
      GT(6)=-2.3311779643E+2
      GT(7)=3.7784390759E+1
      GT(8)=-2.3204806092E+0
      GT(9)=5.3117637687E-2
      EV(1)=-1.0350606586E+1
      EV(2)=4.2903609488E-2
      EV(3)=1.7571599671E+1
      EV(4)=6.1276818706E+3
      EV(5)=-3.0193918656E+3
      EV(6)=1.8873011594E+2
      EV(7)=1.4529023444E+2
      EV(8)=0.162
      FV(1)=1.6969859271
      FV(2)=-.13337234608
      FV(3)=1.4
      FV(4)=168.
      FV(4)=168.
      FT(1)=-.252762921
      FT(2)=.3343285931
      FT(3)=1.12
      FT(4)=168.
      ET(1)=-7.0403639907
      ET(2)=.74421462902
      ET(3)=12.319512908
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      ET(4)=2.2209758501E+3
      ET(5)=-8.8525979933E+2
      ET(6)=72.835897919
      ET(7)=-2.9706914540
      ET(8)=0.1628
C     PARAMETERS FOR THERMODYNAMIC
C     PROPERTIES - MCCARTY, CRYOGENICS
C     VOL 14 NO 5 MAY 1974 AND GOODWIN
C     NBS TECH NOTE 653 APRIL 74
      R=.08205616
      GAMMA=-.0096
      GI(1)=-1.8044750507E+6
      A( 1)=   .183603246136E+02
      A( 2)=  -.182553840603E-01
      A( 3)=   .586623807178E+00
      A( 4)=  -.106005894683E+02
      A( 5)=   .167157622432E+03
      A( 6)=  -.155569173217E+03
      A( 7)=   .106609415022E+03
      A( 8)=  -.341087933790E+02
      A( 9)=   .973203073452E+01
      A(10)=  -.388410018388E+02
      A(11)=   .529573454771E+02
      A(12)=  -.291075304738E+02
      A(13)=   .585307647478E+01
      A(14)=  -.637276532186E+00
      A(15)=   .994444109622E-03
      A(16)=  -.392314821657E-01
      A(17)=   .728820880748E+00
      A(18)=  -.625821815315E+01
      A(19)=   .295561390641E+01
      A(20)=  -.763972649504E+00
      GI(2)=7.7426666393E+4
      GI(3)=-1.3241658754E+3
      GI(4)=1.5438149595E+1
      GI(5)=-5.1479005257E-2
      GI(6)=1.0809172196E-4
      GI(7)=-6.5501783437E-8
      GI(8)=-6.7490056171E+0
      GI(9)=.3E+4
      GI(10)=GI(11)=0
      TO=298.15
      HO=19196.1
      GI(10)=HO-HI(TO)
      TO=300.
      SO=186.4854941
      GI(11)=SO-SI(TO)
      G( 1)= -.187027997685E-01
      G( 2)=  .103387108009E+01
      G( 3)= -.155387625619E+02
      G(4)=  .772311478564E+03
      G( 5)= -.377103300895E+05
      G( 6)=  .846818843475E-03
      G( 7)= -.496415884529E+00
      G( 8)=  .869909352414E+02
      G( 9)= -.322821592493E+05
      G(10)= -.395843026318E-04
      G(11)=  .266772318035E-01
      G(12)= -.304010057839E+01
      G(13)=  .191584507536E-03
      G(14)= -.195587933458E-03
      G(15)=  .607479967879E+01
      G(16)= -.529609525984E-03
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      G(17)=  .152264286004E-04
      G(18)= -.109952182842E-01
      G(19)=  .191395549929E-03
      G(20)=  .386470003746E+05
      G(21)= -.157930582612E+07
      G(22)=  .195270144401E+03
      G(23)=  .165996081629E+07
      G(24)=  .603051146711E+00
      G(25)=  .376485162808E+02
      G(26)=  .125593680622E-02
      G(27)= -.343570032513E+02
      G(28)= -.540945094139E-05
      G(29)=  .185622284663E-02
      G(30)=  .770786979245E-08
      G(31)= -.286868318650E-05
      G(32)=  .372376961647E-04
      DTP=.2815114381423E+02
      DTPV=.1590041545160E-01
      VP(1)=4.77748580
      VP(2)=1.76065363
      VP(3)=-.56788894
      VP(4)=1.32786231
      VP(5)=1.5
      VP(6)=.1158993
      VP(7)=90.68
      VP(8)=190.555
      VP(9)=0.0
      TCC=VP(8)
       PCC=VPN(TCC)*1.01325
      PTP=VP(6)*1.01325
      TTP=VP(7)
      TUL=500.
      TLL=TTP
      PUL=350.
      DCC=10.23
      RETURN
      END
      SUBROUTINE DATA N2
      DIMENSION G(32),VP(9),GI(11)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      DIMENSION A(20)
      COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
      COMMON/SATC/A,DTPV
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/SEN/BETA,XO,DELTA,E1, E2, AGAM
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/CPID/GI
      COMMON/ISP/N,NW,NWW
      NWW=0
      PRINT 100
  100 FORMAT(* THE RANGE OF TEMPERATURE FOR NITROGEN IS 63.15 TO 1900K*
     1/* WITH PRESSURES TO 10000 BAR*)
      N=0 $ NW=1
      EM=28.016 $ EOK=118. $ RM=3.933E-08 $ TC=126.24
      DC=.3139 $ X=1.67108 $ PC=33.98 $ SIG=3.54
      XO=0.164 $ BETA=0.355 $ DELTA=4.352 $ E1=2.17 $ E2=0.287
      AGAM=1.190
C     PARAMETERS FOR TRANSPORT
C     PROPERTIES FROM HANLEY ET. AL.
C     JOUR. PHY. CHEM. REF DATA VOL3, NO 4
C     1974
      GV(1)=-1.8224240000E+2  $  GV(2)=1.9915327374E+2
      GV(3)=-9.1542324494E+1  $  GV(4)=2.3255484059E+1
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      GV(5)=-3.6307214228  $  GV(6)=3.6457506811E-1
      GV(7)=-2.2261880817E-2  $  GV(8)=7.8053904895E-4
      GV(9)=-1.1894029104E-5
      GT(1)=-2.0029573972E+4  $  GT(2)=4.9765746684E+3
      GT(3)=8.0188959378E+3  $  GT(4)=-5.5022716888E+3
      GT(5)=1.5363738965E+3  $  GT(6)=-2.2974737257E+2
      GT(7)=1.9360547346E+1  $  GT(8)=-8.5677385768E-1
      GT(9)=1.5564670935E-2
      EV(1)=-9.8255690362 $ EV(2)=5.7156092139E-001
      EV(3)=1.6094611148E+001 $ EV(4)=3.6954086158E+003
      EV(5)=-8.0889801180E+002 $ EV(6)=6.8464435640E+001
      EV(7)=-2.1241135912  $ EV(8)=0.315
      FV(1)=-1.1217739623 $ FV(2)=0.32912317244
      FV(3)=1.4  $  FV(4)=118.
      FT(1)=.53875666637  $  FT(2)=.061027911104
      FT(3)=1.2  $  FT(4)=118.
      ET(1)=-2.9402951255E+1  $  ET(2)=3.7201743333E+1
      ET(3)=-3.9013509079E+1  $  ET(4)=-3.1826109485E+1
C     THERMODYNAMIC PROPERTIES FROM
C     NBS TECH NOTE 648 - DEC 77
C     JACOBSEN ET. AL.
      R=8.20539E-2
      GAMMA=-.0056
      GI(1)=   -0.735210401157252E 03
      GI(2)=    0.342239980411978E 02
      GI(3)=   -0.557648284567620E 00
      GI(4)=    0.350404228308756E 01
      GI(5)=   -0.173390185081005E-04
      GI(6)=    0.174650849766463E-07
      GI(7)=   -0.356892033544348E-11
      GI(8)=    0.100538722808834E 01
      GI(9)=    0.335340610000000E 04
      TO=298.15  $  SO=191.502  $  HO=8669.0
      GI(10)=GI(11)=0
      GI(10)=HO-HI(TO)
      GI(11)=SO-SI(TO)
      G( 1)=    0.136224769272827E-02
      G( 2)=    0.107032469908591E 00
      G( 3)=   -0.243900721871413E 01
      G( 4)=    0.341007449376470E 02
      G( 5)=   -0.422374309466167E 04
      G( 6)=    0.105098600246494E-03
      G( 7)=   -0.112594826522081E-01
      G( 8)=    0.142600789270907E-03
      G( 9)=    0.184698501609007E 05
      G(10)=    0.811140082588776E-07
      G(11)=    0.233011645038006E-02
      G(12)=   -0.507752586350986E 00
      G(13)=    0.485027881931214E-04
      G(14)=   -0.113656764115364E-02
      G(15)=   -0.707430273540575E 00
      G(16)=    0.751706648852680E-04
      G(17)=   -0.111614119537424E-05
      G(18)=    0.368796562233495E-03
      G(19)=   -0.201317691347729E-05
      G(20)=   -0.169717444755949E 05
      G(21)=   -0.119719240044192E 06
      G(22)=   -0.975218272038281E 02
      G(23)=    0.554639713151823E 05
      G(24)=   -0.179920450443470E 00
      G(25)=   -0.256582926077184E 01
      G(26)=   -0.413707715090789E-03
      G(27)=   -0.256245415300293E 00
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      G(28)=    -0.124222373740063E-06
      G(29)=     0.103556535840165E-04
      G(30)=    -0.538699166558303E-09
      G(31)=    -0.757415412839596E-08
      A( 1)=  -.158453465507E+02
      A( 2)=   .419136911423E-01
      A( 3)=  -.101965371660E+01
      A( 4)=   .134763743799E+02
      A( 5)=  -.109930399087E+03
      A( 6)=   .925518835497E+02
      A( 7)=  -.956233831320E+02
      A( 8)=   .100104366710E+03
      A( 9)=  -.701857937398E+02
      A(10)=   .900076998647E+01
      A(11)=   .286981120347E+02
      A(12)=  -.216767601780E+02
      A(13)=   .496558226471E+01
      A(14)=   .218307928477E+02
      A(15)=  -.126493309807E+00
      A(16)=   .241544188633E+01
      A(17)=  -.245256871794E+02
      A(18)=   .935925207124E+02
      A(19)=  -.360938251632E+02
      A(20)=   .757453271989E+01
      G(32)=     0.585367172069521E-07
      VP(1)=5.1113192094 $ VP(2)=6.482667539E-1
      VP(3)=-1.5108730916E-1 $ VP(4)=7.4028493342E-1
      VP(5)=1.5 $ VP(6)=.123 $ VP(7)=63.15 $ VP(8)=126.26
      VP(9)=0.0
      DTP=.3097717741477E+2
      DTPV=.242822085710E-1
      TCC=VP(8)
      PCC=VPN(TCC)*1.01325
      PTP=VP(6)*1.01325
      TTP=VP(7)
      TLL=TTP
      TUL=1900.
      PUL=10000.
      DCC=11.21
      RETURN  $  END
      SUBROUTINE DATA AR
      DIMENSION G(32),VP(9),GI(11)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      DIMENSION A(20)
      COMMON/SEN/BETA,XO,DELTA,E1, E2, AGAM
      COMMON/SATC/A,DTPV
      COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/CPID/GI
      COMMON/ISP/N,NW,NWW
      NWW=0
      N=0 $ NW=1
      EM=39.948 $ EOK=152.8 $ RM=3.669E-08 $ TC=150.725
      DC=0.533 $ X=1.7124 $ PC=47.983 $ SIG=3.297
      XO=0.183  $ BETA=0.355  $ DELTA=4.352      $ E1=2.27  $E2=0.287
      AGAM=1.190
C     TRANSPORT PROPERTIES
C     FROM HANLEY ET. AL.
C     J. PHY. CHEM. REF DATA VOL 3
C     NO 4 1974
      GV(1)=6.1145472787E+1
      GV(2)=-1.0394390312E+2
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      GV(3)=6.7594614619E+1
      GV(4)=-2.2536509380E+1
      GV(5)=4.2593950138
      GV(6)=-4.7252671093E-1
      GV(7)=3.1795275425E-2
      GV(8)=-1.1629083780E-3
      GV(9)=1.8043010592E-5
      GT(1)=6.2777703742E+3 $ GT(2)=-9.6096376637E+3
      GT(3)=5.8887549191E+3 $ GT(4)=-1.8920926320E+3
      GT(5)=3.4886571437E+2 $ GT(6)=-3.8016786193E+1
      GT(7)=2.5207283167 $ GT(8)=-9.1098744478E-2
      GT(9)=1.3990842942E-3
      EV(1)=-1.0010993993E+1  $  EV(2)=2.0694685712E-1
      EV(3)=1.6029145122E+1  $  EV(4)=1.1717461351E+3
      EV(5)=-5.6995898780E+2  $  EV(6)=4.0136071933E+1
      EV(7)=3.9870122403E+1  $  EV(8)=.537
        FV(1)=1.4653652433 $ FV(2)=-0.77487424965
      FV(3)=1.4  $  FV(4)=152.8
      FT(1)=.2414210327  $  FT(2)=.075696234255
      FT(3)=1.  $  FT(4)=152.8
      ET(1)=-2.4116686960E+1
      ET(2)=                     3.0694859971E+1
      ET(3)=2.2956551674E+3
      ET(4)=                    -3.5559415848E+2
C     TRANSPORT PROPERTIES FROM
C     HANLEY ET. AL. J. PHY. CHEM. REF
C     DATA VOL 3 NO 4 1974 AND
C     GOSMAN ET. AL. NSRDS MON 27 1964
      R=.08205616
      GAMMA=-.0055
      GI(1)=GI(2)=GI(3)=0
      GI(4)=GI(9)=2.5
      GI(5)=GI(6)=GI(7)=0
      GI(8)=0
      GI(10)=GI(11)=0
      TO=87.28  $  SO=129.1786  $  HO=9504.8916
      GI(10)=HO-HI(TO)
      GI(11)=SO-SI(TO)
      G(1)=3.4342657242351E-3
      G(2)=5.7857036681387E-2
      G(3)=-2.6982470812264E+0
      G(4)=1.6481655285291E+2
      G(5)=-1.2849472420416E+4
      G(6)=-3.2636490894686E-4
      G(7)=2.4629470190841E-1
      G(8)=-6.9585445697842E+1
      G(9)=1.9196156939788E+4
      G(10)=1.6603909805594E-5
      G(11)=-1.0860316345366E-2
      G(12)=3.3231759004885E+0
      G(13)=2.1776361947053E-5
      G(14)=5.1615085812771E-3
      G(15)=-1.1366705407293E+0
      G(16)=-2.9018517618859E-4
      G(17)=3.7898289698060E-6
      G(18)=1.1030489790987E-3
      G(19)=-1.4674092942955E-5
      G(20)=-1.1479610716179E+4
      G(21)=-3.9393312963830E+5
      G(22)=-9.9620084307336E+1
      G(23)=-1.8575347046011E+4
      G(24)=-2.9393483871136E-1
      G(25)=1.6408588086762E+1
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      G(26)=-4.0447174229355E-4
      G(27)=-2.0820007165976E+0
      G(28)=-5.4969320649612E-7
      G(29)=7.5137405277667E-5
      G(30)=-2.8667425518207E-10
      G(31)=-6.3003722866834E-8
      G(32)=2.5287413440936E-6
      A( 1)=  -.270262923777E+02
      A( 2)=   .131040241866E+00
      A( 3)=  -.267486438128E+01
      A( 4)=   .300176804406E+02
      A( 5)=  -.875899149326E+02
      A( 6)=  -.408267436456E+02
      A( 7)=   .104268066451E+03
      A( 8)=  -.671278555379E+02
      A( 9)=   .151002935701E+02
      A(10)=  -.331243536637E+02
      A(11)=   .633146212581E+02
      A(12)=  -.427149706899E+02
      A(13)=   .100599900030E+02
      A(14)=   .137682084900E+02
      A(15)=  -.664630363191E-01
      A(16)=   .133368782730E+01
      A(17)=  -.144371463244E+02
      A(18)=   .601938472000E+02
      A(19)=  -.230888463887E+02
      A(20)=   .465318358887E+01
      VP(1)=3.4151115519  $  VP(2)=1.1910812519
      VP(3)=-3.407632334E-1 $ VP(4)=8.9555855251E-1
      VP(5)=1.5 $ VP(6)=.68005 $ VP(7)=83.80 $ VP(8)=150.86
      VP(9)=0.0
      DTP=.3540027619188E+02
      DTPV=.1029227022329
      PRINT 100
  100 FORMAT(* THE TEMPERATURE RANGE FOR ARGON IS 83.8 TO 400 K*
     1/* WITH PRESSURES TO 1000 BAR*)
      TCC=VP(8)
      PCC=VPN(TCC)*1.01325
      PTP=VP(6)*1.01325
      TTP=VP(7)
      TUL=400.
      TLL=TTP
      PUL=1000.
      DCC=13.41
      RETURN  $ END
      SUBROUTINE DATA 02
      DIMENSION G(32),VP(9),GI(11)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      DIMENSION A(20)
      COMMON/SATC/A,DTPV
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/SEN/BETA,X0,DELTA,E1, E2, AGAM
      COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/ISP/N,NW,NWW
      COMMON/CPID/GI
      NWW=0
      N=0 $ NW=1
       X0=0.183  $ BETA=0.355 $ DELTA=4.352 $ E1=2.21 $ E2=0.287
       EM=31.9988 $ EOK=113.0 $ RM=3.8896E-08$ TC=154.575
       DC=0.4362 $ X=2.210636 $ PC=49.770 $ SIG=3.437
      AGAM = 1.190
C     TRANSPORT PROPERTIES
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C       FROM HANLEY ET. AL.
C       VOL 3, NO 4, 1974
        GV(1)=-9.7076378593E+1  $  GV(2)=8.2801254201E+1
        GV(3)=-2.4668758803E+1 $ GV(4)=2.1324360243
        GV(5)=3.7851049522E-1  $  GV(6)=-1.0487216090E-1
        GV(7)=1.1134441304E-2  $  GV(8)=-5.3676093757E-4
        GV(9)=1.0279379641E-5
        GT(1)=-2.0395052193E+5  $  GT(2)=2.4088141709E+5
        GT(3)=-1.2014175183E+5  $  GT(4)=3.295494919E+4
        GT(5)=-5.4244239598E+3  $  GT(6)=5.4734865540E+2
        GT(7)=-3.2854821539E+1  $  GT(8)=1.0753572103
        GT(9)=-1.4610986820E-2
        EV(1)=-1.2152387017E+1  $  EV(2)=-3.1421728994E-1
        EV(3)=1.8201161468E+1  $  EV(4)=2.7390429525E+2
        EV(5)=-2.7498956948E+3  $  EV(6)=2.4340689667E+2
        EV(7)=1.1911504104E+2 $  EV(8)=.435
         FV(1)=4.3526515153 $ FV(2)= -2.0361263878
        FV(3)=1.4  $  FV(4)=100.
        FT(1)=.3060      $FT(2)=.2785
        FT(3)=1.12  $  FT(4)=100.
        ET(1)=-1.2310400765E+1  $  ET(2)=1.6799504261E+1
        ET(3)=-2.9944878721E+3  $  ET(4)=4.7350508788E+2
C       THERMODYNAMIC PROPERTIES
C       FROM WEBER - TO BE PUBLISHED
        R=8.20539E-2
        GAMMA=-.0056
         GI(1)=   -0.498199853711943E 04
         GI(2)=    0.230247779995218E 03
         GI(3)=   -0.345565323510732E 01
         GI(4)=    0.352187677367116E 01
         GI(5)=   -0.435420216024420E-04
         GI(6)=    0.134635345013162E-07
         GI(7)=    0.162059825959105E-10
         GI(8)=    0.103146851572565E 01
        GI(9)=    0.223918105000000E 04
        GI(10)=GI(11)=0
        TO=298.15  $  HO=8682.  $  SO=205.037
        GI(10)=HO-HI(TO)
        G(1)=   -.4308768468E-03
        G(2)=    .1979591095E+00
        G(3)=   -.4143014968E+01
        G(4)=    .1853654396E+03
        G(5)=   -.1270637452E+05
        G(6)=    .1536388737E-04
        G(7)=    .1326068945E-02
        G(8)=   -.2199275123E+01
        G(9)=    .4705445127E+04
        G(10)=   .4728198017E-06
        G(11)=   .2430408198E-02
        G(12)=  -.1896759615E+00
        G(13)=  -.6887067207E-05
        G(14)=  -.6132885180E-03
        G(15)=  -.1836518694E+00
        G(16)=   .2575663871E-04
        G(17)=  -.2415604646E-06
        G(18)=   .1438680831E-03
        G(19)=  -.1703915986E-05
        G(20)=  -.2353705917E+04
        G(21)=  -.2271707669E+06
        G(22)=  -.2753815471E+02
        G(23)=   .9277648729E+05
        G(24)=  -.4114926856E-01
        G(25)=   .1982233262E+01
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      G(26)=  -.1239651142E-03
      G(27)=  -.6322588664E+00
      G(28)=  -.2443207666E-07
      G(29)=   .1328704370E-04
      G(30)=  -.1146313812E-09
      G(31)=  -.1021169305E-07
      G(32)=   .2334998237E-06
      GI(11)=SO-SI(TO)
      A( 1)=   .581394753076E+02
      A( 2)=  -.490241196133E-01
      A( 3)=   .168328893252E+01
      A( 4)=  -.325161223398E+02
      A( 5)=   .550300989872E+03
      A( 6)=  -.510968506115E+03
      A( 7)=   .315091559049E+03
      A( 8)=  -.232566659258E+02
      A( 9)=  -.488425479359E+02
      A(10)=  -.150624217523E+03
      A(11)=   .280441603851E+03
      A(12)=  -.176693896861E+03
      A(13)=   .403247747449E+02
      A(14)=   .252198688365E+01
      A(15)=  -.136098316472E-01
      A(16)=   .282316159403E+00
      A(17)=  -.286645905341E+01
      A(18)=   .617024212284E+01
      A(19)=  -.810220795462E+00
      A(20)=  -.279601068969E+00
      VP(1)=7.568956  $  VP(2)=5.004836  $  VP(3)=-2.137460
      VP(4)=3.454481  $  VP(5)=1.514  $  VP(6)=.0014606
      VP(7)=54.359  $  VP(8)=154.581
      VP(9)=0.0
      DTP=.4081997364372E+02
      DTPV=.3318894767078E-03
      PRINT 100
  100 FORMAT(* THE TEMPERATURE RANGE FOR OXYGEN IS 54.359 TO 400 K*
     1/* WITH PRESSURES TO 1200 BAR*)
      TCC=VP(8)
      PCC=VPN(TCC)*1.01325
      PTP=VP(6)*1.01325
      TTP=VP(7)
      TUL=400.
      TLL=TTP
      PUL=1200.
      DCC=13.63
      RETURN  $  END
      SUBROUTINE DATA P H2
      DIMENSION G(32),VP(9),GI(11)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      DIMENSION A(20)
      COMMON/SATC/A,DTPV
      COMMON/CPID/GI
      COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/PARA/PERCEN
      COMMON/ISP/N
      N=1
      GO TO 1
      ENTRY N H2
      N=2
      GO TO 1
      ENTRY O H2
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      N=3
      GO TO 1
      ENTRY E H2
      N=4
      GO TO 1
      ENTRY F H2
      N=5
    1 CONTINUE
C     NO TRANSPORT PROPERTIES FOR HYDROGEN
C     THERMODYNAMIC PROPERTIES FROM
C     RODER AND MCCARTY IR 75-814 AND
C     IR 74-357
      R=.08205616
      GAMMA=-.0041
      G( 1)  = 4.614387755654E-4
      G( 2)  = 4.233184556086E-2
      G( 3)  =-5.096556226503E-1
      G( 4)  = 2.923059738269E+0
      G( 5)  =-2.987609147211E+1
      G( 6)  = 1.883148601410E-5
      G( 7)  =-1.322256954639E-3
      G( 8)  = 3.016504431701E-1
      G( 9)  = 5.093705560851E+1
      G(10)  = 1.973828324919E-7
      G(11)  = 2.858492039828E-4
      G(12)  =-2.228279239123E-2
      G(13)  =-2.257481136764E-6
      G(14)  = 2.414272369746E-5
      G(15)  =-1.695713398588E-3
      G(16)  =-5.393676391275E-7
      G(17)  = 3.998955244328E-9
      G(18)  = 1.142457561274E-6
      G(19)  =-1.252566225896E-8
      G(20)  =-4.917861934882E+1
      G(21)  =-1.585666017368E+2
      G(22)  =-1.901602946272E-1
      G(23)  = 9.198020862500E+0
      G(24)  =-3.180455518810E-4
      G(25)  = 1.191057791926E-3
      G(26)  =-3.791352773225E-7
      G(27)  =-3.983377699095E-5
      G(28)  =-1.234510854688E-10
      G(29)  = 1.950266293499E-9
      G(30)  =-2.380343917109E-13
      G(31)  =-4.073576608192E-13
      A( 1)=   .916617720187E+02
      A( 2)=  -.179492524446E+00
      A( 3)=   .454671158395E+01
      A( 4)=  -.658499589788E+02
      A( 5)=   .734466804535E+03
      A( 6)=  -.682501045175E+03
      A( 7)=   .631783674710E+03
      A( 8)=  -.539408873282E+03
      A( 9)=   .430923811783E+03
      A(10)=  -.300295738811E+03
      A(11)=   .156567165346E+03
      A(12)=  -.504103608225E+02
      A(13)=   .720706926514E+01
      A(14)=  -.123944440318E+03
      A(15)=   .140334800142E+01
      A(16)=  -.211023804313E+02
      A(17)=   .173254622817E+03
      A(18)=  -.444294580871E+03
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      A(19)=    .138699365355E+03
      A(20)=  -.235774161015E+02
      G(32)   = 8.801354930777E-12
      VP(1)=3.05300134164
      VP(2)=2.80810925813
      VP(3)=-0.655461216567
      VP(4)=1.59514439374
      VP(5)=1.5814454428
      VP(7)=13.8
      VP(6)=0.0695
      VP(8)=32.938
      VP(9)=0
      DTP=.3821428945438E+02
      DTPV=.6322296353698E-01
      EM=2.01594
      PRINT 100
  100 FORMAT(* THE TEMPERATURE RANGE FOR HYDROGEN IS 13.8 TO 400 K*
     1/* WITH PRESSURES TO 1200 BAR*)
      TCC=VP(8)
      PCC=VPN(TCC)*1.01325
      PTP=VP(6)*1.01325
      TTP=VP(7)
      TUL=400.
      TLL=TTP
      PUL=1200.
      DCC=15.556
      RETURN
      END
      SUBROUTINE PROPS(PP,DD,TT)
C THE 32 TERM EQUATION OF STATE, INPUT IS DENSITY(MOLES/L),
C TEMPERATURE(K), OUTPUT (PP) IS PRESSURE IN ATM,OR DP/DD IN
C LITER-ATM/MOLE OR DP/DT ATM/K OR S,H,OR CV AT ONE LIMIT OF
C INTEGRATION
      DIMENSION X(33)
      DIMENSION B(33),G(32)
      EQUIVALENCE (B,X)
      COMMON/DATA/G,R,GAMMA
      COMMON/1/B
      DATA(ID=1)
      DATA(IZ=1)
    1 CONTINUE
      IF(IZ.LE.0)GO TO 2
      IZ=0
    2 CONTINUE
      D=DD
      P=PP
      T=TT
      GM=GAMMA
      D2=D*D
      D3=D2*D
      D4=D3*D
      D5=D4*D
      D6=D5*D
      D7=D6*D
      D8=D7*D
      D9=D8*D
      D10=D9*D
      D11=D10*D
      D12=D11*D
      D13=D12*D
      TS=SQRT (T)
      T2=T*T
      T3=T2*T
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      T4=T3*T
      T5=T4*T
      F=EXP (GM*D2)
      GO TO (100,200,300,400,500,600,700),K
      ENTRY PRESS
C     ENTRY FOR PRESSURE, INPUT IS DENSITY
C     AND TEMP. IN MOL/L AND K, OUTPUT IS IN ATM.
      K=1
      GO TO 1
  100 CONTINUE
      B( 1)=D2*T
      B( 2)=D2*TS
      B( 3)=D2
      B( 4)=D2/T
      B( 5)=D2/T2
      B( 6)=D3*T
      B( 7)=D3
      B( 8)=D3/T
      B( 9)=D3/T2
      B(10)=D4*T
      B(11)=D4
      B(12)=D4/T
      B(13)=D5
      B(14)=D6/T
      B(15)=D6/T2
      B(16)=D7/T
      B(17)=D8/T
      B(18)=D8/T2
      B(19)=D9/T2
      B(20)=D3*F/T2
      B(21)=D3*F/T3
      B(22)=D5*F/T2
      B(23)=D5*F/T4
      B(24)=D7*F/T2
      B(25)=D7*F/T3
      B(26)=D9*F/T2
      B(27)=D9*F/T4
      B(28)=D11*F/T2
      B(29)=D11*F/T3
      B(30)=D13*F/T2
      B(31)=D13*F/T3
      B(32)=D13*F/T4
      IF(ID.GT.0)GO TO 102
      B(33)=P-R*D*T
      RETURN
  102 P=0
      M=32
      DO 101 I=1,M
  101 P=P+B(I)*G(I)
      P=P+R*D*T
      PP=P
      RETURN
      ENTRY DPDD
C     PARTIAL OF PRESSURE WITH RESPECT TO
C     DENSITY - SEE PRESSURE
C     ENTRY FOR UNITS
      K=2
      GO TO 1
  200 CONTINUE
      F1=2.00*F*GM*D
      F21=3.000*F*D2 +F1*D3
      F22=5.000*F*D4 +F1*D5
      F23=7.000*F*D6 +F1*D7
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      F24=9.000*F*D8 +F1*D9
      F25=11.00*F*D10+F1*D11
      F26=13.00*F*D12+F1*D13
      B( 1)=2.00*D*T
      B( 2)=2.00*D*TS
      B( 3)=2.00*D
      B( 4)=2.00*D/T
      B( 5)=2.00*D/T2
      B( 6)=3.00*D2*T
      B( 7)=3.00*D2
      B( 8)=3.00*D2/T
      B( 9)=3.00*D2/T2
      B(10)=4.00*D3*T
      B(11)=4.00*D3
      B(12)=4.00*D3/T
      B(13)=5.00*D4
      B(14)=6.00*D5/T
      B(15)=6.00*D5/T2
      B(16)=7.00*D6/T
      B(17)=8.00*D7/T
      B(18)=8.00*D7/T2
      B(19)=9.00*D8/T2
      B(20)=F21/T2
      B(21)=F21/T3
      B(22)=F22/T2
      B(23)=F22/T4
      B(24)=F23/T2
      B(25)=F23/T3
      B(26)=F24/T2
      B(27)=F24/T4
      B(28)=F25/T2
      B(29)=F25/T3
      B(30)=F26/T2
      B(31)=F26/T3
      B(32)=F26/T4
      M=32
      IF(ID.GT.0)GO TO 202
      B(33)=P-R*T
      RETURN
  202 P=0
      DO 201 I=1,M
  201 P=P+B(I)*G(I)
      P=P+R*T
      PP=P
      RETURN
      ENTRY DPDT
C     PARTIAL OF PRESSURE WITH RESPECT
C     TO TEMPERATURE - SEE PRESSURE
C     ENTRY FOR UNITS
      K=3
      GO TO 1
  300 CONTINUE
      X( 1)=D2
      X( 2)=D2/(2.00*TS)
      X( 3)=0
      X( 4)=-D2/T2
      X( 5)=-2.00*D2/T3
      X( 6)=D3
      X( 7)=0
      X( 8)=-D3/T2
      X( 9)=-2.00*D3/T3
      X(10)=D4
      X(11)=0
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      X(12)=-D4/T2
      X(13)=0
      X(14)=-D6/T2
      X(15)=-2.00*D6/T3
      X(16)=-D7/T2
      X(17)=-D8/T2
      X(18)=-2.00*D8/T3
      X(19)=-2.00*D9/T3
      X(20)=-2.00*D3*F/T3
      X(21)=-3.00*D3*F/T4
      X(22)=-2.00*D5*F/T3
      X(23)=-4.00*D5*F/T5
      X(24)=-2.00*D7*F/T3
      X(25)=-3.00*D7*F/T4
      X(26)=-2.00*D9*F/T3
      X(27)=-4.00*D9*F/T5
      X(28)=-2.00*D11*F/T3
      X(29)=-3.00*D11*F/T4
      X(30)=-2.00*D13*F/T3
      X(31)=-3.00*D13*F/T4
      X(32)=-4.00*D13*F/T5
      IF(ID.GT.0)GO TO 302
      X(33)=PP-R*D
      RETURN
  302 P=0
      DO 301 I=1,32
  301 P=P+G(I)*X(I)
      PP=P+R*D
      RETURN
      ENTRY DSDN
C     PARTIAL OF ENTROPY WITH
C     RESPECT TO THE G COEFFICIENTS
      K=4
      GO TO 1
  400 CONTINUE
C     S=SO-R*LOGF(D*R*T/PO)+(DSDN(D)-DSDN(0))*101.325 +CPOS(T)
      G1=F/(2.00*GM)
      G2=(F*D2-2.00*G1)/(2.00*GM)
      G3=(F*D4-4.00*G2)/(2.00*GM)
      G4=(F*D6-6.00*G3)/(2.00*GM)
      G5=(F*D8-8.00*G4)/(2.00*GM)
      G6=(F*D10-10.00*G5)/(2.00*GM)
      X( 1)=-D
      X( 2)=-D/(2.00*TS)
      X( 3)=0.D0
      X( 4)=+D/T2
      X( 5)=2.00*D/T3
      X( 6)=-D2/2.00
      X( 7)=0.D0
      X( 8)=D2/(2.00*T2)
      X( 9)=D2/T3
      X(10)=-D3/3.00
      X(11)=0.D0
      X(12)=D3/(3.00*T2)
      X(13)=0.D0
      X(14)=D5/(5.00*T2)
      X(15)= 2.00*D5/(5.00*T3)
      X(16)=D6/(6.00*T2)
      X(17)=D7/(7.00*T2)
      X(18)=2.00*D7/(7.00*T3)
      X(19)=D8/(4.00*T3)
      X(20)=2.00*G1/T3
      X(21)=3.00*G1/T4
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      X(22)=2.00*G2/T3
      X(23)=4.00*G2/T5
      X(24)=2.00*G3/T3
      X(25)=3.00*G3/T4
      X(26)=2.00*G4/T3
      X(27)=4.00*G4/T5
      X(28)=2.00*G5/T3
      X(29)=3.00*G5/T4
      X(30)=2.00*G6/T3
      X(31)=3.00*G6/T4
      X(32)=4.00*G6/T5
      IF(ID.GT.0)GO TO 402
      RETURN
  402 P=0
      DO 401 I=1,32
  401 P=P+G(I)*X(I)
      PP=P
      RETURN
      ENTRY DUDN
C     TERMS NEEDED FOR ENTHALPY CALCULATION
      K=5
      GO TO 1
  500 CONTINUE
C     H=H0+(T*DSDN(D)-DSDN(0))*101.325+(DUDN(D-DUDN(0))*101.325+CPOH(T)
C     +(P/D-R*T)*101.325
      G1=F/(2.00*GM)
      G2=(F*D2-2.00*G1)/(2.00*GM)
      G3=(F*D4-4.00*G2)/(2.00*GM)
      G4=(F*D6-6.00*G3)/(2.00*GM)
      G5=(F*D8-8.00*G4)/(2.00*GM)
      G6=(F*D10-10.00*G5)/(2.00*GM)
      X( 1)=D*T
      X( 2)=D*TS
      X( 3)=D
      X( 4)=D/T
      X( 5)=D/T2
      X( 6)=D2*T/2.00
      X( 7)=D2/2.00
      X( 8)=D2/(2.00*T)
      X( 9)=D2/(2.00*T2)
      X(10)=D3*T/3.00
      X(11)=D3/3.00
      X(12)=D3/(3.00*T)
      X(13)=D4/4.00
      X(14)=D5/(5.00*T)
      X(15)=D5/(5.00*T2)
      X(16)=D6/(6.00*T)
      X(17)=D7/(7.00*T)
      X(18)=D7/(7.00*T2)
      X(19)=D8/(8.00*T2)
      X(20)=G1/T2
      X(21)=G1/T3
      X(22)=G2/T2
      X(23)=G2/T4
      X(24)=G3/T2
      X(25)=G3/T3
      X(26)=G4/T2
      X(27)=G4/T4
      X(28)=G5/T2
      X(29)=G5/T3
      X(30)=G6/T2
      X(31)=G6/T3
      X(32)=G6/T4
```

```
      IF(ID.GT.0)GO TO 502
      RETURN
  502 P=0
      DO 501 I=1,32
  501 P=P+G(I)*X(I)
      PP=P
      RETURN
      ENTRY TDSDT
C     TEMP. TIMES THE PARTIAL OF
C     ENTROPY WITH RESPECT TO TEMP.
      K=6
      GO TO 1
  600 CONTINUE
C     CV=CV0+(TDSDN(/)-TDSDN(D))*101.325
      G1=F/(2.00*GM)
      G2=(F*D2-2.00*G1)/(2.00*GM)
      G3=(F*D4-4.00*G2)/(2.00*GM)
      G4=(F*D6-6.00*G3)/(2.00*GM)
      G5=(F*D8-8.00*G4)/(2.00*GM)
      G6=(F*D10-10.00*G5)/(2.00*GM)
      X(1)=0
      X( 2)=-D/(4.00*TS)
      X(3)=0
      X( 4)=2.00*D/T2
      X( 5)=6.00*D/T3
      X(6)=0
      X(7)=0
      X( 8)=D2/T2
      X( 9)=3.00*D2/T3
      X(10)=0
      X(11)=0
      X(12)=(2.00*D3)/(3.00*T2)
      X(13)=0
      X(14)=(2.00*D5)/(5.00*T2)
      X(15)=(6.00*D5)/(5.00*T3)
      X(16)=D6/(3.00*T2)
      X(17)=(2.00*D7)/(7.00*T2)
      X(18)=(6.00*D7)/(7.00*T3)
      X(19)=(3.00*D8)/(4.00*T3)
      X(20)=6.000*G1/T3
      X(21)=12.00*G1/T4
      X(22)=6.000*G2/T3
      X(23)=20.00*G2/T5
      X(24)=6.000*G3/T3
      X(25)=12.00*G3/T4
      X(26)=6.000*G4/T3
      X(27)=20.00*G4/T5
      X(28)=6.000*G5/T3
      X(29)=12.00*G5/T4
      X(30)=6.000*G6/T3
      X(31)=12.00*G6/T4
      X(32)=20.00*G6/T5
      IF(ID.GT.0)GO TO 602
      RETURN
  602 P=0
      DO 601 I=1,32
  601 P=P+G(I)*X(I)
      PP=P
      RETURN
      ENTRY DP2D2
C     SECOND PARTIAL OF PRESSURE WITH
C     RESPECT TO DENSITY SQUARED
      K=7
```

```
      GO TO 1
  700 CONTINUE
      F1=2.*F*GM*D
      F12=2.*F1*GM*D+2.*F*GM
      F212=3.*F1*D2+3.*2.*D*F+F12*D3+F1*3.*D2
      F222=5.*F1*D4 +5.*4.*D3*F+5.*D4*F1+F12*D5
      F232=7.*F1*D6+7.*6.*D5*F+7.*D6*F1+F12*D7
      F242=9.*F1*D8+9.*8.*D7*F+9.*D8*F1+F12*D9
      F252=11.*F1*D10+10.*11.*D9*F+11.*D10*F1+F12*D11
      F262=13.*F1*D12+13.*12.*D11*F+13.*D12*F1+F12*D13
      B(1)=2.*T  $B(2)=2.*TS  $  B(3)=2.
      B(4)=2./T  $  B(5)=2./T2  $  B(6)=6.*D*T
      B(7)=6.*D  $  B(8)=6.*D/T  $  B(9)=6.*D/T2
      B(10)=12.*D2*T  $  B(11)=12.*D2  $  B(12)=12.*D2/T
      B(13)=20.*D3  $  B(14)=30.*D4/T  $  B(15)=30.*D4/T2
      B(16)=42.*D5/T  $  B(17)=56.*D6/T  $  B(18)=56.*D6/T2
      B(19)=72.*D7/T2  $  B(20)=F212/T2  $  B(21)=F212/T3
      B(22)=F222/T2
      B(23)=F222/T4  $  B(24)=F232/T2  $  B(25)=F232/T3
      B(26)=F242/T2  $  B(27)=F242/T4  $  B(28)=F252/T2
      B(29)=F252/T3  $  B(30)=F262/T2  $  B(31)=F262/T3
      B(32)=F262/T4
      M=32
      IF(ID.GT.0)GO TO 702
      B(33)=PP
      RETURN
  702 P=0
      DO 701 I=1,M
  701 P=P+B(I)*G(I)
      PP=P
      RETURN
      END
      FUNCTION VPN(TT)
C     CALCULATES VAPOR PRESSURE IN ATMOSPHERES
C     FOR AN INPUT TEMPERATURE IN KELVIN
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP
      T=TT
      X=(1.-VP(7)/T)/(1.-VP(7)/VP(8))
      VPN=VP(6)*EXP (VP(1)*X+VP(2)*X*X+VP(3)*X**3+VP(9)*X**4+VP(4)*X*
     1(1.-X)**VP(5))
      RETURN
      END
      FUNCTION FINDTV(POBS)
C     ITTERATES THE VAPOR PRESSURE EQUATION
C     FOR A TEMPERATURE ( IN KELVIN)
C     GIVEN AN INPUT PRESSURE IN ATMOSPHERES
      COMMON/DATA/G,R,GAMMA,VP,DTP
      DIMENSION G(32),VP(9)
      T=VP(8)
      DO 7 I=1,10
      P=VPN(T)
      IF(ABS (P-POBS)-.000001*POBS)8,8,6
    6 CONTINUE
      CORR=(POBS-P)/DPDTVP(T)
    7 T=T+CORR
    8 CONTINUE
      FINDTV=T
      RETURN
      END
      FUNCTION CV(D,T)
C     CALCULATES SPECIFIC HEAT CAPACITY
C     AT CONSTANT VOLUME FOR AN INPUT
```

```
C     OF DENSITY AND TEMPERATURE IN MOL/L AND K
      DATA(R=8.31434)
      DD=D
      TT=T
      CALL TDSDT(CD,DD,TT)
      DD=0
      CALL TDSDT(CO,DD,TT)
      CV=CPI(TT)+(CO-CD)*101.325
      CV=CV-R
      RETURN
      END
      FUNCTION FIND D(P,T)
C     ITTERATES EQUATION OF STATE
C     FOR DENSITY, GIVEN PRESSURE
C     AND TEMP. IN ATM. AND KELVIN.  IF
C     ITTERATION FAILS TRY USING
C     FUNCTION CALLED FIND M
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,PUL,DCC
      TT=T
      IF(TT.GT.VP(8))GO TO 100
      IF( P.GT.VPN(TT))GO TO 101
      DD=SATV(TT)
      GO TO 102
  100 PC=PCC/1.01325
      X=(1.1/(9.*PC))*P+.7/9.
      DD=P/(R*T*X)
      IF(P/PC.GT.20..AND.T/VP(8).LT.2.5)DD=DTP
      GO TO 102
  101 DD=SATL(TT)
  102 CONTINUE
      DO 10 I=1,50
      IF(DD.LE.0.0.OR.DD.GT.50.)GO TO 11
      CALL PRESS(PP,DD,TT)
      IF(PP.LE.0.0)GO TO 11
      P2=PP
      IF(ABS (P-P2)-1.E-7*P)20,20,1
    1 CALL DPDD(PP,DD,TT)
      DP=PP
      CORR=(P2-P)/DP
      IF(ABS (CORR)-1.E-7*DD)20,20,10
   10 DD=DD-CORR
   11 CALL REGULA(P,DD,T)
   20 FIND D=DD
      RETURN
      END
      SUBROUTINE REGULA(PI,DD,TT)
C     ITTERATES EQUATION OF STATE FOR DENSITY WHEN FIND D FAILS
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      T=TT
      P=PI
      D2=0
      IF(T.LT.TCC)GO TO 10
      DO=DCC*TCC/T
      GO TO 20
   10 PP=VPN(T)
      IF(P.GT.PP)GO TO 15
      DO=SATV(T)
      DO 11 I=1,150
      CALL PRESS(PO,DO,T)
      IF(PO.GE.P)GO TO 12
   11 DO=DO+.0001*DO
```

```
      GO TO 42
   12 D1=D0
   13 CALL PRESS(P1,D1,T)
      IF(P1.LT.P)GO TO 14
      IF(D1.LE..1*PTP)GO TO 42
      D0=D1
      Z=(P1-P)/P
      IF(Z.LT..1)Z=.1
      IF(Z.GT..9)Z=.9
      D1=D1-Z*D1
      GO TO 13
   14 CALL PRESS(P0,D0,T)
      DO 140 I=1,50
      D=D1
      P3=P1
      IF(ABS(P-P1).LT..00001*P)GO TO 40
      P2=P-P1
      D1=D1+(D1-D0)*P2/(P1-P0)
      IF(ABS(D-D1).LE..00001*D)GO TO 40
      IF(ABS(P-P1).LT..005*P)D2=FIND M(P,T,D1)
      IF(D2.GT.0.0.AND.D2.LT.50.)D1=D2
      D2=0
      CALL PRESS(P1,D1,T)
      IF(P0.GT.P.AND.P1.GT.P)GO TO 120
      IF(P0.LT.P.AND.P1.LT.P)GO TO 120
      GO TO 140
  120 P0=P3
      D0=D
  140 CONTINUE
      GO TO 41
   15 D0=SATL(T)
      DO 16 I=1,10
      CALL PRESS(P0,D0,T)
      IF(P0.LE.P)GO TO 17
   16 D0=D0-.0001*D0
      GO TO 42
   17 D1=D0
   18 CALL PRESS(P1,D1,T)
      IF(D1.GE.50.)GO TO 42
      IF(P1.GT.P)GO TO 14
      D0=D1
      Z=(P-P1)/P
      Z=Z*10
      IF(T/TCC.LT..6)Z=1.
      IF(Z.LT.1.)Z=1.
      IF(Z.GT.9.)Z=9.
      D1=D1+.01*D1*Z
      GO TO 18
   20 CALL PRESS(P0,D0,T)
      IF(P.LE.P0)GO TO 30
      D1=D0
   21 CALL PRESS(P1,D1,T)
      IF(P1.GE.P)GO TO 14
      IF(D1.GE.50.)GO TO 42
      D0=D1
      Z=(P-P1)/P
      Z=Z*10
      IF(Z.LT.1)Z=1
      IF(Z.GT.9)Z=9
      D1=D1+.1*D1*Z
      GO TO 21
   30 D1=D0
   31 CALL PRESS(P1,D1,T)
```

```
      IF(P1.LE.P)GO TO 14
      IF(D1.LE..1*PTP)GO TO 42
      DO=D1
      Z=(P1-P)/P
      Z=Z*10
      IF(Z.LT.1)Z=1
      IF(Z.GT.9)Z=9
      D1=D1-.1*D1*Z
      GO TO 31
   40 DD=D1
      RETURN
   41 PRINT 101,P,T,D
  102 FORMAT(* REGULA FAILED AT P=*,F7.2,* AND T=*,F7.2)
  101 FORMAT(* DENSITY ITTERATION FAILED AT P=*,F7.2,* AND T=*,F7.2,
     1/* DENSITY RETURNED IS*,E17.8)
      RETURN
   42 PRINT 102,P,T
      RETURN
      END
      FUNCTION CP(D,T)
C     CALCULATES SPECIFIC HEAT CAPACITY
C     AT CONSTANT PRESSURE FOR INPUT OF
C     DENSITY AND TEMPERATURE IN MOL/L AND K
C     CP IS IN JOULES/MOL-K
      CVEE=CV(D,T)
      CALL DPDT(DPT,D,T)
      CALL DPDD(DPD,D,T)
      CP=CVEE+(T/(D**2)*(DPT**2)/DPD)*101.325
      RETURN
      END
      FUNCTION DPDTVP(TT)
C     CALCULATES THE DERIVATIVE OF PRESSURE
C     WITH RESPECT TO TEMPERATURE AT
C     SATURATION.  INPUT IS TEMP. IN K, OUTPUT IS ATM/K.
      COMMON/DATA/G,R,GAMMA,VP
      DIMENSION G(32),VP(9)
      T=TT
      IF(TT.GT.VP(8))GO TO 1
      X=(1.-VP(7)/T)/(1.-VP(7)/VP(8))
      DXDT=(VP(7)/T**2)/(1.-VP(7)/VP(8))
      DPDT=VP(1)*DXDT+2.*VP(2)*X*DXDT+VP(3)*3.*X**2*DXDT+VP(4)*
     1((1.-X)**VP(5))*DXDT+VP(4)*X*((1.-X)**(VP(5)-1.))*VP(5)*(-DXDT)
      DPDT=DPDT*VPN(T)
      DPDTVP=DPDT
      RETURN
    1 DPDTVP=0
      RETURN
      END
      FUNCTION FIND M(P,T,DD)
C     ALTERNATIVE FOR FIND D, INPUT IS
C     PRESSURE IN ATM., T IN KELVIN AND
C     DENSITY IN MOL/L.  INPUT DENSITY
C     IS A STARTING VALUE FOR ITTERATION
C     OF EQUATION OF STATE FOR SOLUTION FOR P AND T
      TT=T
      DO 10 I=1,50
      CALL PRESS(PP,DD,TT)
      P2=PP
      IF(ABS (P-P2)-1.E-7*P)20,20,1
    1 CALL DPDD(PP,DD,TT)
      DP=PP
      CORR=(P2-P)/DP
      D=DD
```

```
      IF(ABS (CORR)-1.E-7*D)20,20,10
   10 DD=DD-CORR
      FIND M=0
      RETURN
   20 FIND M=DD
      RETURN
      END
      FUNCTION ENTHAL(P,D,T)
C     CALCULATES ENTHALPY FOR INPUT OF
C     PRESSURE, DENSITY AND TEMP. IN
C     ATM., MOL/L AND K.  OUTPUT IS IN
C     JOULES/MOL
      R=.08205616
      DD=D
      TT=T
      CALL DSDN(SD,DD,TT)
      CALL DUDN(UD,DD,TT)
      DD=0
      CALL DSDN(SO,DD,TT)
      CALL DUDN(UO,DD,TT)
      ENTHAL=T*(SD-SO)*101.325+(UD-UO)*101.325+HI(T)+(P/D-R*T)*101.325
      RETURN
      END
      FUNCTION ENTROP(D,T)
C     CALCULATES ENTROPY
C     FOR AN INPUT OF DENSITY AND
C     TEMP. IN MOL/L AND K.  OUTPUT IS IN
C     JOULES/MOL-K
      R=.08205616
      DD=D
      TT=T
      CALL DSDN(SD,DD,TT)
      DD=0
      CALL DSDN(SO,DD,TT)
      ENTROP=(SD-SO)*101.325-R*ALOG(D*R*T)*101.325+SI(T)
      RETURN
      END
      FUNCTION SATL(TT)
C     CALCULATES THE DENSITY OF THE
C     SATURATED LIQUID AT TEMP., T IN KELVIN.
C     OUTPUT IS IN MOL/L.
      DIMENSION A(20)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/SATC/A,DTPV
      K=14
      KK=7
      GO TO 10
      ENTRY SATV
      K=1
      KK=13
   10 IF(T.GE.TCC)GO TO 20
      T=TT
      ITT=TCC
      IF(ITT+1-T.LT.1.)T=ITT
      X=(T-TCC)/(TTP-TCC)
      D=A(K)*ALOG(X)
      DO 11 I=2,KK
      K=K+1
      MM=I
      IF(MM.GE.5)MM=MM+1
   11 D=D+A(K)*(1.-X**((MM-5)/3.))
      IF(K.LT.14)GO TO 12
```

```
      D=DCC+EXP(D)*(DTP-DCC)
      GO TO 13
   12 D=DCC+EXP(D)*(DTPV-DCC)
   13 SATL=D
      IF(ITT+1-TT.LT.1.)SATL=D-(D-DCC)*(TT-T)
      RETURN
   20 DSATL=DCC
      RETURN
      END
      FUNCTION SOUND(D,T)
C     CALCULATES THE SPEED OF SOUND
C     FOR AN INPUT OF DENSITY AND TEMP.
C     IN MOL/L AND KELVIN.  OUTPUT IS IN
C     METERS/SECOND.
      COMMON/CRIT/W
      CALL DPDD(DP,D,T)
      SOUND=((CP(D,T)/CV(D,T))*DP*101325./W)**.5
      RETURN
      END
      FUNCTION VISC(DD,T)
C     RETURNS VISCOSITY IN (G/CM-S)*E+6,
C     T IN K, D IN MOL/L
      COMMON/CRIT/EM
      D=DD*EM/1000.
      VISC=DILV(T)+FDCV(D,T)+EXCESV(D,T)
      RETURN
      END
      FUNCTION THERM(DD,T)
C     RETURNS TC IN MW/M-K, T IN K, D IN MOL/L
      COMMON/HAN/CR,TCI
      COMMON/ISP/N,NW
      COMMON/CRIT/EM
      D=DD*EM/1000.
      IF(NW.EQ.0 ) GO TO 3
      CR=CRITC(D,T)
      THER=DILT(T)+FDCT(D,T)*100.+EXCEST(D,T)+CR
      TCI=THER-CR
       THERM=THER
      RETURN
    3 CR=CRITC(D,T)
      THERM=DILT(T)+FDCT(D,T)+EXCEST(D,T)+CR
      TCI=THERM-CR
      RETURN
      END
      FUNCTION EXCESV(D,T)
C     CALCULATES EXCESS VISCOSITY
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/ISP/N,NW
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      R2=D**(.5)*((D-EV(8))/EV(8))
      R=D**(.1)
      X=EV(1)+EV(2)*R2+EV(3)*R+EV(4)*R2/(T*T)+EV(5)*R/T**(1.5)+EV(6)/T
     1+EV(7)*R2/T
      X1=EV(1)+EV(6)/T
      EXCESV=EXP (X)-EXP (X1)
      RETURN
      ENTRY EXCEST
C     CALCULATES EXCESS THERMAL CONDUCTIVITY
       IF(NW.EQ.0 ) GO TO 3
      R=D**(.1)
      X=ET(1)+ET(2)*R+ET(3)*R/T**(1.5)+ET(4)/T
      X1=ET(1)+ET(4)/T
      EXCESV=(EXP (X)-EXP (X1))/10.
      RETURN
```

```
    3 R2=D**(.5)*((D-ET(8))/ET(8))
      R=D**(.1)
      X=ET(1)+ET(2)*R2+ET(3)*R+ET(4)*R2/(T*T)+ET(5)*R/T**(1.5)+ET(6)/T
     1+ET(7)*R2/T
      X1=ET(1)+ET(6)/T
      EXCESV=EXP (X)-EXP (X1)
      RETURN
      END
      FUNCTION FDCV(D,T)
C     FIRST DENSITY CORRECTION
C     FOR VISCOSITY AND THERMAL CONDUCTIVITY
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      FDCV=(FV(1)+FV(2)*(FV(3)-ALOG(T/FV(4)))**2)*D
      RETURN
      ENTRY FDCT
      FDCV=(FT(1)+FT(2)*(FT(3)-ALOG(T/FT(4)))**2)*D
      RETURN
      END
       FUNCTION CRITC(D,T)
C     CALCULATES CRITICAL ENHANCEMENT
C     FOR THERMAL CONDUCTIVITY
      COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
      COMMON/CHECK/DELD,DELT,DSTAR,TSTAR
      COMMON/HJM/EPSI,CPCV,RRR,AKT
      COMMON/ISP/N,NW,NWW
C D IN G/CM3 , T IN K
C  OUTPUT UNITS ARE MW/M.K
      AV=6.0225E+23 $ BK=1.38054E-16
       DELD=ABS (D-DC)/DC $ DELT=ABS (T-TC)/TC
C  CALCULATE DISTANCE PARAMETER
      R=(RM**2.5)*(D**0.5)*(AV/EM)**0.5
      R=R*(EOK**0.5)*X/(T**0.5)
      RRR=R
C   GENERAL  EQUATION
      DX=D*1000.0/EM
      CALL DPDT(DPT,DX,T)
C  DPDT  IN  ATS PER DEG.
      DPT=DPT*1.01325E+6
C  DPDT NOW IN DYNES PRR DEG
      CALL DPDD(DPD,DX,T)
C  DPDD UN ATS, MOL/L
      DPD=DPD*(1.01325E+6)*(1000.0/EM)
CDPDD NOW IN DYNES, GM/CM3
      IF( DPD.LT.0.0) DPD=1.0
   94 VIS=VISC(DX,T)*(1.0E-06)
C   VISCOSITY IN GM/CM.S
      IF(DELD.EQ.0.25. OR. DELD.LT. 0.25) 8,10
    8 IF(DELT.EQ.0.025. OR. DELT.LT.0.025 ) 9, 10
    9 COMPRES=SENG(D,T)
      GO TO 12
   10 COMPRES=1.0/(D*DPD)**0.5
   12 EX=BK*T**2*(DPT**2)*COMPRES
      EXB=R*((BK*T)**0.5)*(D**0.5)*((AV/EM)**0.5)
      CRIT=EX/(EXB*6.0*3.14159*VIS)
C   PUT IN DAMPING FACTOR
      BDD=((D-DC)/DC)**4
      BTT=((T-TC)/TC)**2
      FACT=EXP (-18.66*BTT - 4.25*BDD)
      DELC=CRIT*FACT/100.0
      CRITC=DELC
       AKT=COMPRES*COMPRES
      EPSI=R*R*BK*T*(AV*D/EM)*AKT
      EPSI=EPSI**0.5
```

```
C    CALC  CP-CV
       CPCV=T*(DPT**2)*AKT/D
       RETURN
        END
       FUNCTION SENG(D,T)
C      SCALED EQUATION OF STATE FOR CRITICAL REGION
       COMMON/CRIT/ EM, EOK, RM, TC, DC, X , PC, SIG
       COMMON/SEN/BETA,XO,DELTA,E1, E2, AGAM
       COMMON/CHECK/DELD,DELT,DSTAR,TSTAR
       DSTAR= D/DC $ TSTAR=T/TC
       BETO=1./BETA
       XX=DELT/DELD**BETO
       AG=AGAM-1.0
        BET2= 2.0*BETA
       AGB=AG/BET2
       DEL1=DELTA-1.0
        AGBB=(AG-BET2)/BET2
       XXO=(XX+ XO)/XO
       XXB=XXO**BET2
       BRAK=1.0 + E2*XXB
        BRAK1=BRAK**AGB
       H=E1*XXO*BRAK1
       HPRIM=(E1/XO)*BRAK1 + (AG/XO)*E1*E2*(XXB)*(BRAK**AGBB)
       RCOM=(DELD**DEL1)*(DELTA*H - (XX/BETA)*HPRIM   )
       RCOMP=1.0/(RCOM*DSTAR**2)
       RCM=RCOMP/(PC*1.01325E+06)
C    RCM IN DYNES
       RCM=RCM**0.5
C
        SENG=RCM
        RETURN
        END
       FUNCTION DILV(T)
C      GIVES DILUTE GAS VISCOSITY AND THERMAL
C      CONDUCTIVITY FOR AN INPUT TEMP. IN
C      KELVIN.  OUTPUT UNITS ARE SAME AS
C      THOSE IN VISC AND THERM
       COMMON/ISP/N,NW,NWW
       COMMON/DATA1/GV,GT,FV,FT,EV,ET
       DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
       SUM=0
       TF=T**(1./3.)
       TFF=T**(-4./3.)
       DO 10 I=1,9
       TFF=TFF*TF
    10 SUM=SUM+GV(I)*TFF
       IF(NWW.EQ.7) GO TO 9
       DILV=SUM*1000.
       GO TO 11
     9 DILV=SUM
    11 RETURN
       ENTRY DILT
       TF=T**(1./3.)
       TFF=T**(-4./3.)
       SUM=0
       DO 20 I=1,9
       TFF=TFF*TF
    20 SUM=SUM+GT(I)*TFF
       DILV=SUM
       RETURN
       END
       FUNCTION CPI(T)
C      CALCULATES IDEAL GAS THERMO PROPERTIES
```

```
C     FOR ALL FLUIDS EXCEPT H2.  INPUT IS IN
C     KELVIN, OUTPUT IS IN JOULES, MOL/L AND K
      COMMON/CPID/G(11)
      COMMON/ISP/N
      IF(N.NE.0)GO TO 5
      K=1
    1 U=G(9)/T
      EU=EXP (U)
      TS=1./T**4
      GO TO (2,3,4),K
    2 CPI=G(8)*U*U*EU/(EU-1.)**2
      DO 10 I=1,7
      TS=TS*T
   10 CPI=CPI+G(I)*TS
      CPI=CPI*8.31434
      RETURN
    5 CPI=CPO(T,N)
      RETURN
      ENTRY SI
      IF(N.NE.0)GO TO 6
      K=2
      GO TO 1
    3 CPI=G(8)*(U/(EU-1.)-ALOG(1.-1./EU))
     1-G(1)*TS*T/3.-G(2)*TS*T*T/2.-G(3)/T+G(4)*ALOG(T)+G(5)*T+G(6)*T*T/2
     2.+G(7)*T**3/3.
      CPI=CPI*8.31434+G (11)
      RETURN
    6 CPI=CPOS(T,N)
      RETURN
      ENTRY HI
      IF(N.NE.0)GO TO 7
      K=3
      GO TO 1
    4 CPI=G(8)*U*T/(EU-1.)-G(1)/(2.*T*T)-G(2)/T+G(3)*ALOG(T)+G(4)*T
     1+G(5)*T*T/2.+G(6)*T**3/3.+G(7)*T**4/4.
      CPI=CPI*8.31434+G(10)
      RETURN
    7 CPI=CPOH(T,N)
      RETURN
      END
      FUNCTION CPO(TI,N)
      DIMENSION T(58),CPP(58),CPN(58),CPO(58),CPE(58)
      COMMON/PARA/PERCEN
C     CALCULATES IDESL GAS SPECIFIC HEAT FOR H2 BY INTERPOLATING
C     DATA TAKEN FROM RP 1932, UNITS OF THE TABLES ARE  CAL/MOL DEG 5.
C     UNITS OF OUTPUT ARE JOULES/MOL DEG K.  THE INDEX N DETERMINES THE
C     SPECIES,FOR N=1,PARAHYDROGEN,N=2 NORMAL, N=3 ORTHO, N=4 EQUILIB
C     N=5,SOME ORTHO-PARA MIXTURE SPECIFIED BY COMMON /PARA/,PERCENT
C     RANGE OF TEMP IS FROM 10 TO 5000K.
      DATA(T=
     1 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
     2 50.0, 55.0, 60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0,100.0,
     3105.0,110.0,115.0,120.0,125.0,130.0,135.0,140.0,145.0,150.0,160.0,
     4170.0,180.0,190.0,200.0,210.0,220.0,230.0,240.0,250.0,260.0,270.0,
     5280.0,290.0,300.0,350.0,400.0,500.0,600.,700.,1000.,1500.,2000.,
     63000.,4000.,5000.)
      DATA((CPE(I),I=1,58)=4.968   ,4.96884,4.97647,5.01153,5.07451,5.208
     11,5.83508,6.81282,7.87989,8.60613,9.00231,9.08005,8.93278,8.65894,
     28.33603,8.01207,7.71009,7.4416,7.21109,7.01858,6.85857,6.72557,6.6
     32055,6.53555,6.46904,6.42003,6.38403,6.36151,6.34602,6.33753,6.340
     401,6.34577,6.37276,6.413,6.45925,6.50975,6.5605,6.6095,6.65724,
     7                                  6.692,6.734,6.771,6.804,6.832,
     56.856,6.877,6.895,6.950,6.974,6.993,7.009,7.036,7.219,7.720,8.195,
```

```
     68.859,9.342,9.748)
      DATA(CPO=
     14.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,
     24.968,4.968,4.968,4.969,4.972,4.975,4.981,4.990,5.002,5.018,5.039,
     35.064,5.094,5.129,5.169,5.213,5.261,5.313,5.369,5.427,5.487,5.612,
     45.741,5.868,5.992,6.109,6.219,6.320,6.411,6.493,6.566,6.629,6.684,
     56.732,6.773,6.808,6.917,6.962,6.993,7.009,7.036,7.219,7.720,8.195,
     68.859,9.342,9.748)
      DATA(CPP=
     14.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.969,4.972,4.983,
     25.006,5.048,5.114,5.207,5.328,5.475,5.646,5.835,6.036,6.245,6.454,
     36.659,6.854,7.037,7.203,7.351,7.480,7.590,7.681,7.753,7.807,7.870,
     47.883,7.858,7.808,7.742,7.667,7.591,7.516,7.445,7.380,7.322,7.270,
     57.225,7.186,7.152,7.050,7.010,6.998,7.010,7.037,7.219,7.720,8.159,
     68.859,9.342,9.748)
      DATA(CPN=
     14.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.969,4.972,
     24.977,4.988,5.005,5.029,5.061,5.100,5.147,5.201,5.261,5.325,5.393,
     35.463,5.534,5.606,5.677,5.748,5.816,5.882,5.947,6.008,6.067,6.177,
     46.276,6.366,6.446,6.517,6.581,6.638,6.687,6.731,6.769,6.802,6.831,
     56.855,6.876,6.894,6.950,6.974,6.993,7.009,7.036,7.219,7.720,8.195,
     68.859,9.342,9.748)
      GO TO(1,2,3,4,5),N
    1 CPO=ATKINT(TI,CPP,T,58, 6,NES,.01)*4.184
      RETURN
    2 CPO=ATKINT(TI,CPN,T,58, 6,NES,.01)*4.184
      RETURN
    3 CPO=ATKINT(TI,CPO,T,58, 6,NES,.01)*4.184
      RETURN
    4 CPO=ATKINT(TI,CPE,T,58, 6,NES,.01)*4.184
      RETURN
    5 TUP=TI+.5
      TDN=TI-.5
      HUP=CPOH(TUP,5)
      HDN=CPOH(TDN,5)
      CPO=(HUP-HDN)
      RETURN
      END
      FUNCTION CPOH(TI,N)
      DIMENSION T(58),HP(58),HN(58),HO(58),HE(58)
      COMMON/PARA/PERCEN
C     CALCULATES THE ENTHALPY OF THE IDEAL GAS FOR H2 BY INTERPOLATION
C     DATA TAKEN FROM RP 1932, UNITS OF TABLES ARE CAL/MOL
C     UNITS OF OUTPUT ARE JOULE/MOL.  THE INDEX N DETERMINES THE SPECIES
C     SPECIES,FOR N=1,PARAHYDROGEN,N=2 NORMAL, N=3 ORTHO, N=4 EQUILIB
C     N=5,SOME ORTHO-PARA MIXTURE SPECIFIED BY COMMON /PARA/,PERCENT
C     RANGE OF TEMP IS FROM 10 TO 5000K.
      DATA(T=
     1 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
     2 50.0, 55.0, 60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0,100.0,
     3105.0,110.0,115.0,120.0,125.0,130.0,135.0,140.0,145.0,150.0,160.0,
     4170.0,180.0,190.0,200.0,210.0,220.0,230.0,240.0,250.0,260.0,270.0,
     5280.0,290.0,300.0,350.0,400.0,500.0,600.,700.,1000.,1500.,2000.,
     63000.,4000.,5000.)
      DATA(HN=
     1 303.67, 313.60, 323.54, 333.48, 343.41, 353.35, 378.19, 403.03,
     1 427.86, 452.71, 477.56, 502.43, 527.34, 552.32, 577.40, 602.62,
     3 628.02, 653.64, 679.51, 705.66, 732.13, 758.92, 786.06, 813.55,
     4 841.40, 869.61, 898.17, 927.08, 956.33, 985.91,1015.80,1045.99,
     51107.22,1169.49,1232.71,1296.78,1361.60,1427.10,1493.20,1559.84,
     61626.93,1694.44,1762.30,1830.48,1898.91,1967.57,2036.43,2382.74,
     72730.94,3429.46,4129.51,4831.66,6966.23,10697.2,14679.2,
     823230.9,32345.,41895.)
```

```
 DATA(HP=
1  49.68,  59.61,  69.55,  79.49,  89.42,  99.36, 124.20, 149.04,
2 173.88, 198.73, 223.61, 248.58, 273.71, 299.11, 324.90, 351.22,
3 378.22, 406.01, 434.71, 464.38, 495.09, 526.84, 559.62, 593.41,
4 628.14, 663.75, 700.14, 737.23, 774.92, 813.10, 851.69, 890.60,
5 969.04,1047.84,1126.58,1204.93,1282.69,1359.74,1436.03,1511.56,
61586.36,1660.49,1733.99,1806.95,1879.42,1951.47,2023.15,2377.83,
72729.17,3429.24,4129.48,4831.65,6966.23,10697.2,14679.2,
823230.9,32345.,41895.)
 DATA(HO=
1 388.33, 398.27, 408.20, 418.14, 428.07, 438.01, 462.85, 487.69,
2 512.53, 537.37, 562.21, 587.05, 611.89, 636.73, 661.57, 686.42,
3 711.29, 736.18, 761.11, 786.09, 811.14, 836.28, 861.54, 886.93,
4 912.49, 938.23, 964.18, 990.37,1016.80,1043.51,1070.50,1097.78,
51153.27,1210.04,1268.09,1327.39,1387.91,1449.56,1512.26,1575.93,
61640.46,1705.76,1771.74,1838.32,1905.41,1972.94,2040.86,2384.38,
72731.52,3429.53,4129.52,4831.66,6966.23,10697.2,14679.2,
823230.9,32345.,41895.)
 DATA(HE=
1  49.68,  59.62,  69.57,  79.56,  89.66,  99.96, 127.50, 159.12,
2 195.77, 236.90, 280.97, 326.24, 371.33, 415.35, 457.86, 498.74,
3 538.05, 575.93, 612.56, 648.13, 682.82, 716.78, 750.14, 783.03,
4 815.54, 847.76, 879.77, 911.63, 943.40, 975.11,1006.80,1038.52,
51102.11,1166.03,1230.39,1295.23,1360.58,1426.43,1492.76,1559.55,
61626.75,1694.32,1762.23,1830.43,1898.88,1967.55,2036.42,2382.74,
72730.94,3429.46,4129.51,4831.66,6966.23,10697.2,14679.2,
823230.9,32345.,41895.)
 GO TO(1,2,3,4,5),N
1 CPOH=ATKINT(TI,HP,T,58, 6,NES,.01)*4.184
  RETURN
2 CPOH=ATKINT(TI,HN,T,58, 6,NES,.01)*4.184
  RETURN
3 CPOH=ATKINT(TI,HO,T,58, 6,NES,.01)*4.184
  RETURN
4 CPOH=ATKINT(TI,HE,T,58,6 ,NES,.01)*4.184
  RETURN
5 PERCE  =PERCEN /100.
  CPOH=(ATKINT(TI,HO,T,58,6,NES,.01)*(1.-PERCE  )+
 1ATKINT(TI,HP,T,58,6,NES,.01)*PERCE  )*4.184
  RETURN
  END
  FUNCTION CPOS(TI,N)
  DIMENSION T(60),SP(60),SN(60),SO(60),SE(60)
  COMMON/PARA/PERCEN
C     CALCULATES  THE ENTROPY OF THE IDEAL GAS FOR H2 BY INTERPOLATING
C     DAKEN FROM RP 1932, UNITS OF THE TABLES ARE CAL/MOL DEG K.  1
C     UNITS OF OUTPUT ARE JOULES/MOL DEG K.  THE INDEX N DETERMINES THE
C     SPECIES,FOR N=1,PARAHYDROGEN,N=2 NORMAL, N=3 ORTHO, N=4 EQUILIB
C     N=5,SOME ORTHO-PARA MIXTURE SPECIFIED BY COMMON /PARA/,PERCENT
C     RANGE OF TEMP IS FROM 10 TO 5000K.
  DATA(T=
 1 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
 2 50.0, 55.0, 60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0,100.0,
 3105.0,110.0,115.0,120.0,125.0,130.0,135.0,140.0,145.0,150.0,160.0,
 4170.0,180.0,190.0,200.0,210.0,220.0,230.0,240.0,250.0,260.0,270.0,
 5280.0,290.0,300.0,350.0,400.0,450.0,500.0,550.0,600.0,700.,1000.,
 61500.,2000.,3000.,4000.,5000.)
  DATA(SP=
 U11.214,12.120,12.886,13.549,14.135,14.658,15.766,16.672,17.438,
 I18.102,18.688,19.214,19.693,20.135,20.548,20.938,21.310,21.669,
 022.017,22.356,22.688,23.014,23.334,23.648,23.957,24.260,24.557,
 424.848,25.132,25.410,25.681,25.945,26.451,26.929,27.379,27.802,
 528.201,28.577,28.932,29.268,29.586,29.889,30.177,30.452,30.716,
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630.969,31.212,32.305,33.244,34.069,34.806,35.473,36.082,37.165,
739.701,42.720,45.007,51.221,53.839,55.969)
  DATA(SO=
115.581,16.486,17.252,17.916,18.501,19.024,20.133,21.038,21.804,
222.468,23.053,23.576,24.050,24.482,24.880,25.248,25.591,25.912,
326.215,26.500,26.771,27.029,27.275,27.512,27.739,27.958,28.170,
428.375,28.575,28.769,28.958,29.143,29.502,29.846,30.177,30.498,
530.808,31.109,31.401,31.684,31.958,32.225,32.484,32.735,32.979,
633.216,33.446,34.505,35.432,36.253,36.989,37.656,38.265,39.348,
741.884,44.903,47.190,51.221,53.839,55.969)
  DATA(SN=
115.607,16.512,17.278,17.941,18.527,19.050,20.159,21.064,21.830,
222.494,23.079,23.603,24.078,24.513,24.914,25.288,25.638,25.969,
326.283,26.582,26.868,27.143,27.407,27.663,27.911,28.151,28.384,
428.611,28.832,29.047,29.256,29.461,29.856,30.234,30.595,30.942,
531.274,31.594,31.901,32.197,32.483,32.758,33.025,33.282,33.531,
733.772,34.005,35.073,36.003,36.825,37.561,38.228,38.836,39.920,
742.455,45.475,47.762,51.221,53.839,55.969)
  DATA(SE=
111.215,12.120,12.887,13.554,14.149,14.692,15.918,17.069,18.196,
219.294,20.331,21.285,22.145,22.911,23.592,24.198,24.740,25.229,
325.674,26.080,26.455,26.804,27.129,27.435,27.724,27.999,28.260,
428.510,28.750,28.980,29.203,29.418,29.828,30.216,30.584,30.934,
531.269,31.591,31.899,32.196,32.482,32.758,33.024,33.282,33.531,
633.772,34.005,35.073,36.003,36.825,37.561,38.228,38.836,39.920,
742.455,45.475,47.762,51.221,53.839,55.969)
  GO TO(1,2,3,4,5),N
1 CPOS=ATKINT(TI,SP,T,60, 6,NES,.01)*4.184
  RETURN
2 CPOS=ATKINT(TI,SN,T,60, 6,NES,.01)*4.184
  RETURN
3 CPOS=ATKINT(TI,SO,T,60, 6,NES,.01)*4.184
  RETURN
4 CPOS=ATKINT(TI,SE,T,60, 6,NES,.01)*4.184
  RETURN
5 PERCE  =PERCEN /100.
  CPOS=(ATKINT(TI,SO,T,60,6,NES,.01)*(1.-PERCE  )+
 1ATKINT(TI,SP,T,60,6,NES,.01)*PERCE  )*4.184
C   THE EXPRESSION FOR THE ENTROPY OF EQUILIBRIUM H2 IS INCORRECT,
C   THE ENTROPY OF MIXING MUXT BE ADDED TO MAKE IT COMPLETE
  RETURN
  END
  FUNCTION ATKINT(X,YMAT,XMAT,NELMTS,NMAX,NESSY,ACRCY)
C   THIS PROGRAM HAS BEEN CHANGED SO THAT THE OSCILLATING NATURE OF
C   THE MATRIX TO BE INTERPOLATED EXISTS ONLY AT THE UPPER END OF THE
C   TABLE
C   THIS ROUTINE WILL TAKE INPUT MATRICES OF UP TO 999 ELEMENTS EACH,
C   ARRANGED SO THAT THE X MATRIX(XMAT) IS IN EITHER ASCENDING OR
C   DESCENDING ORDER,SELECT NMAX OF THESE POINTS,CHOSEN SO THAT
C   SUCESSIVE X VALUES OSCILATE ABOUT THE VALUE OF THE ARGUMENT X
C   UNLESS THE ENDS OF THE XMATRIX INTERFERE (IN THIS CASE THE
C   OSCILATORY NATURE IS LOST BUT THE PROGRAM WILL STILL PERFORM AN
C   INTERPOLATION), INTERPOLATE ON THESE NMAX PAIRS OF DATA BY
C   AN OSCILATING VARIABLE POINT AITKEN INTERPOLATION ALGORITHM
C   EITHER UNTIL THE PERCENTAGE CHANGE IN THE INTERPOLANT IS LESS
C   THAN THE ACRCY ARGUMENT(THE ARGUMENT NESSY INDICATES THE
C   NUMBER OF THE POINT JUST BEFORE THE LAST ONE CHECKED) OR UNTIL
C   THE NMAX POINTS ARE ALL USED.  IT IS SUGGESTED THAT NMAX
C   BE LESS THAN 10, AND OF COURSE LESS THAN NELMTS.  NELMTS
C   INDICATES THE NUMBER OF ELEMENTS IN XMAT OR YMAT.
C   IF NESSY IS ZERO IT INDICATES THAT THE INTERPOLATION REQUIREMENT
C   HAS NOT BEEN SATISFIED.  IF NESSY IS 1 IT MEANS THAT THE VALUE OF
C   X LIES OUT SIDE THE RANGE OF XMAT.
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      DIMENSION YMAT(999), XMAT(999),A(21,20)
  100 FORMAT(42HINTERPOLATION REQUIREMENT NOT SATISFIED(X=,E16.8,1H)/33H
     1LAST 2 APPROXIMATIONS OF Y ARE(Y=,E16.8,1H,,E16.8,1H))
  200 FORMAT(55HTHIS REPRESENTS AN EXTRAPOLATION OF THE  XMAT MATRIX(X=,
     1E16.8,1H)/33HNO CALCULATION HAS BEEN PERFORMED)
  300 FORMAT(24HNELMTS IS LESS THAN NMAX)
  400 FORMAT(22HNMAX IS LARGER THAN 20)
      IF(NMAX-20)71,71,69
   69 PRINT 400
      ATKINT=0.0
      RETURN
   71 IF(NMAX-NELMTS)75,75,73
   73 PRINT 300
      ATKINT=0.0
      RETURN
   75 CONTINUE
C     FIRST TWO SUCCESSIVE VALUES OF THE XMATRIX THAT STRADDLE THE
C     VALUE X WILL BE SOUGHT
      JJ1=NELMTS-1
      DO 20 I=1,JJ1
      DIF1=X-XMAT(I)
      DIF2=XMAT(I+1)-X
      IF(DIF1)16,15,16
   15 ATKINT=YMAT(I)
      NESSY =NMAX
      RETURN
   16 IF(DIF2)18,17,18
   17 ATKINT=YMAT(I+1)
      NESSY =NMAX
      RETURN
   18 RATIO=DIF1/ DIF2
      IF(RATIO)20,20,19
   19 IMID=I
      GO TO 32
   20 CONTINUE
C     AT THIS POINT ONE COULD PRINT THE FOLLOWING STATEMENT
C     WRITE OUTPUT TAPE 6,200,X
      NESSY=1
      ATKINT=0.0
      RETURN
   32 CONTINUE
C     NOTE THAT RATIO IS POSITIVE IF THE TWO POINTS STRADDLE X
C     REGARDLESS WHICH IS LARGER
      JJJ=IMID
      JUP=IMID
      JDN=IMID
      IF(JJJ+NMAX-NELMTS+1)98,98,102
   98 DO 201 J=1,NMAX
      JJJ=IMID+J-1
      A(1,J)=XMAT(JJJ)
  201 A(2,J)=YMAT(JJJ)
      GO TO 203
  102 DO 41 J=1,NMAX
      JJ=J/2
      JOE=J-2*JJ
C     JOE IS 0 IF J IS EVEN AND 1 IF J IS ODD
      IF(J-1)33,40,33
   33 IF(JDN-1)34,36,34
   34 IF(JUP-NELMTS)35,37,35
   35 IF(JOE)37,36,37
   36 JUP=JUP+1
      JJJ=JUP
      GO TO 40
```

```
   37 JDN=JDN-1
      JJJ=JDN
      GO TO 40
   40 A(1,J)=XMAT(JJJ)
      A(2,J)=YMAT(JJJ)
   41 CONTINUE
  203 NNN=NMAX+1
      DO 6 J=3,NNN
      L=J-1
      DO 5 K=L,NMAX
C     J IS THE COLUMN NUMBER
C     K IS THE ROW NUMBER
     0A(J,K)=(A(J-1,K)-A(J-1,J-2))*(X-A(1,J-2))/(A(1,K)-A(1,J-2))
     1      +A(J-1,J-2)
      IF(K-L)3,2,3
    2 IF(ABS((A(J,L)-A(J-1,L-1))/A(J,L))-ACRCY/100.0)7,7,3
    3 CONTINUE
    5 CONTINUE
    6 CONTINUE
      NESSY=0
C     AT THIS POINT ONE COULD PRINT OUT THE FOLLOWING STATEMENT.
C     WRITE OUTPUT TAPE 6,100,X,A(NNN,NMAX),A(NNN-1,NMAX-1)
      ATKINT=A(NNN,NMAX)
      RETURN
    7 NESSY=J-1
      ATKINT=A(J,L)
      RETURN
      END
      SUBROUTINE LIMITS(P,T,IL)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUP
      IF(P.GT.PUP)GO TO 10
      IF(T.GT.TUL.OR.T.LT.TLL)GO TO 12
      IL=1
      RETURN
   10 PRINT 11,PUP
   11 FORMAT(* THE INPUT PRESSURE IS OUT OF THE RANGE OF THIS EQUATION *
     1/* THE RANGE FOR THIS EQUATIONS IS FROM 0 TO *,F6.0,* BAR*)
      IL=0
      RETURN
   12 PRINT 13,TLL,TUL
   13 FORMAT(* THE INPUT TEMPERATURE IS OUT OF RANGE*
     1/* THE RANGE FOR THIS EQUATION IS FROM *,F6.2,* TO *,F6.0,* K*)
      IL=0
      RETURN
      END
      SUBROUTINE DATA NE
      PRINT 105
  105 FORMAT(* THE TEMPERATURE RANGE OF NEON IS 25 TO 300 KELVIN*
     1/* WITH PRESSURES TO 200 BAR*
     2/* YOU MAY ENTER THIS ROUTINE WITH ANY TWO OF THE VARIABLES*
     1/* P,D OR T, AND 0 FOR THE THIRD , FOR SATURATION ENTER WITH*
     4/* EITHER P OR T, AND 0 FOR THE OTHER TWO ,IF YOU WANT *
     5/* TO CHANGE FLUIDS ENTER 0 FOR ALL THREE INPUT VARIABLES*)
      TC=44.4
      PC=26.54
      TTP=25.
      PUL=200.
      TUL=300.
      TLL=25.
      EM=20.183
      PRINT 104
```

```
104 FORMAT(* DO YOU WANT ENGINEERING UNITS OR METRIC UNITS ?*
   1/* ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC*)
    CALL DATA N
    READ 102,IU
102 FORMAT(I1)
 17 IF(IU.EQ.0)GO TO 18
    PRINT 103
103 FORMAT(* ENTER PRESSURE IN BAR, DENSITY IN MOLES/LITER, AND TEMPER
   1ATURE IN KELVINS*)
 24 READ *,P,D,T
    P=P/1.01325
    GO TO 19
 18 PRINT 106
106 FORMAT(* ENTER PRESSURE IN LB/SQ IN, DENSITY IN LB/CU FT AND*
   1/* TEMPERATURE IN DEGREES F*)
    READ *,P,D,T
    P=P/14.695949
    D=D*16.01846371/EM
    IF(T.EQ.0.0)GO TO 19
    T=(T-32.0)/1.8+273.15
 19 CONTINUE
    IF(P.LE.0.0)GO TO 14
    IF(D.LE.0.0)GO TO 13
    IF(T.LE.0.0)GO TO 12
    GO TO 21
 12 IF(P.LE.0.0.OR.D.LE.0.0)GO TO 15
    T=FNDTNE(P,D)
    IF(P.GT.PUL.OR.T.GT.TUL.OR.T.LT.TLL)GO TO 25
    GO TO 16
 13 IF(T.LE.0.0.OR.P.LE.0.0)GO TO 15
    IF(P.GT.PUL.OR.T.GT.TUL.OR.T.LT.TLL)GO TO 25
131 D=FNDDNE(P,T)
    GO TO 16
 14 IF(D.LE.0.0.OR.T.LE.0.0)GO TO 15
    P=FNDPNE(D,T)
    IF(P.GT.PUL.OR.T.GT.TUL.OR.T.LT.TLL)GO TO 25
 16 H=ENTHNE(P,D,T)
    S=ENTRNE(D,T)
    PP=P*1.01325
    IF(IU.EQ.0)GO TO 23
    PRINT 100,PP,D,T,H,S
100 FORMAT(* PRESSURE=*,F7.2,* BAR, DENSITY=*,F7.4,* MOLES/LITER, TE*
   1*MPERATURE=*,F6.2,* KELVIN*
   2/* ENTHALPY=*,F9.2,* JOULES/MOL, ENTROPY=*,F6.2,* JOULES/MOL-K*)
    GO TO 17
 23 PO=P*14.695949
    TO=T*1.8-459.67
    DO=D*EM/16.01846371
    HO=H/(2.324445*EM)
    SO=S/(4.184001*EM)
    PRINT 101,PO,DO,TO,HO,SO
101 FORMAT(* PRESSURE=*,F10.3,* LB/SQ IN, DENSITY=*,F10.4,* LB/CU FT*
   1/* TEMPERATURE=*,F8.2,* F, ENTHALPY=*,F9.2,* BTU/LB*
   2/* ENTROPY=*,F6.2,* BTU/LB-F*)
    GO TO 18
 15 IF(P.LE.0.0.AND.T.LE.0.0)GO TO 21
    IF(P.GT.0.0)GO TO 20
    IF(T.GT.TC.OR.T.LT.TTP)GO TO 22
    P=VPNNE(T)
109 FORMAT(* DO YOU WANT SATURATED LIQUID OR VAPOR*
   1/* ENTER A 1 FOR VAPOR OR A 0 FOR LIQUID*)
    PRINT 109
```

```
      READ *,IP
      IF(IP.GT.0)P=P-.0001
      IF(IP.EQ.0)P=P+.00001
      GO TO 131
   20 IF(P.GT.PC)GO TO 22
      T=VPTENE(P)
      PRINT 109
      READ *,IP
      IF(IP.GT.0)P=P-.0001
      IF(IP.EQ.0)P=P+.00001
      GO TO 131
   22 PRINT 107
  107 FORMAT(* YOUR INPUT PRESSURE OR TEMPERATURE IS OUT OF RANGE*
     1/* OF THE SATURATION CURVE, TC=44.4, PC=26.89, T TRIPLE=25.*
     2/* TRY AGAIN*)
      GO TO 17
   21 RETURN
   25 PRINT 108
  108 FORMAT(* YOUR INPUT TEMPERATURE OR PRESSURE IS OUT OF RANGE*
     1/* TEMP MUST BE BETWEEN 25 AND 300K AND PRESSURE BETWEEN*
     2/* 0 AND 200BAR, TRY AGAIN*)
      GO TO 17
      END
      SUBROUTINE DATA HE
      PRINT 105
  105 FORMAT(* THE TEMPERATURE RANGE OF HELIUM IS 2.177 TO 1500 KELVIN*
     1/* WITH PRESSURES TO 1000 BAR*
     2/* YOU MAY ENTER THIS ROUTINE WITH ANY TWO OF THE VARIABLES*
     3/* P,D OR T, AND 0 FOR THE THIRD, FOR SATURATION ENTER WITH*
     4/* EITHER P OR T, AND A 0 FOR THE OTHER TWO , IF YOU WANT *
     5/* TO CHANGE FLUIDS ENTER A 0 FOR ALL THREE INPUT VARIABLES*)
      TC=5.201
      PC=2.245
      TTP=2.17
      PUL=1000.
      TUL=1500.
      TLL=2.177
      EM=4.0026
      PRINT 104
  104 FORMAT(* DO YOU WANT ENGINEERING UNITS OR METRIC UNITS ?*
     1/* ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC*)
      READ 102,IU
  102 FORMAT(I1)
   17 IF(IU.EQ.0)GO TO 18
      PRINT 103
  103 FORMAT(* ENTER PRESSURE IN BAR, DENSITY IN MOLES/LITER, AND TEMPER
     1ATURE IN KELVINS*)
   24 READ *,P,D,T
      P=P/1.01325
      GO TO 19
   18 PRINT 106
  106 FORMAT(* ENTER PRESSURE IN LB/SQ IN, DENSITY IN LB/CU FT AND*
     1/* TEMPERATURE IN DEGREES F*)
      READ *,P,D,T
      P=P/14.695949
      D=D*16.01846371/EM
      IF(T.EQ.0.0)GO TO 19
      T=(T-32.)/1.8+273.15
   19 CONTINUE
      IF(P.LE.0.0)GO TO 14
      IF(D.LE.0.0)GO TO 13
      IF(T.LE.0.0)GO TO 12
```

```
      GO TO 21
  12  IF(P.LE.0.0.OR.D.LE.0.0)GO TO 15
      T=FNDTHE(P,D)
      IF(P.GT.PUL.OR.T.GT.TUL.OR.T.LT.TLL)GO TO 25
      GO TO 16
  13  IF(T.LE.0.0.OR.P.LE.0.0)GO TO 15
      IF(P.GT.PUL.OR.T.GT.TUL.OR.T.LT.TLL)GO TO 25
 131  D=FNDDHE(P,T)
      GO TO 16
  14  IF(D.LE.0.0.OR.T.LE.0.0)GO TO 15
      P=FNDPHE(D,T)
      IF(P.GT.PUL.OR.T.GT.TUL.OR.T.LT.TLL)GO TO 25
  16  H=ENTHHE(D,T)
      S=ENTRHE(D,T)
      W=SOUNHE(D,T)
      CPP=CPHE(D,T)
      CVV=CVHE(D,T)
      TH=THERHE(D,T)*100.
      V=VISCHE(D,T)
      PP=P*1.01325
      IF(IU.EQ.0)GO TO 23
      PRINT 100,PP,D,T,H,S,CPP,CVV,W,TH,V
 100  FORMAT(* PRESSURE=*,F8.2,* BAR, DENSITY=*,F7.4,* MOLES/LITER. TE*
     1*MPERATURE=*,F7.2,* KELVIN*
     2/* ENTHALPY=*,F9.2,* JOULES/MOL, ENTROPY=*,F6.2,* JOULES/MOL-K*
     3/* CP=*,F7.2,* JOULES/MOL-K, CV=*,F7.2,* JOULES/MOL-K*
     4/* SPEED OF SOUND=*,F8.2,* METERS/SEC*
     5/* THERMAL CONDUCTIVITY=*,F7.2,* M WATS/M-K*
     6/* VISCOSITY=*,F7.2,* MICRO G/CM-SK)
      GO TO 17
  23  PO=P*14.695949
      TO=T*1.8-459.67
      DO=D*EM/16.01846371
      HO=H/(2.324445*EM)
      SO=S/(4.184001*EM)
      CPPO=CPP/(4.184001*EM)
      CVVO=CVV/(4.184001*EM)
      WO=W*3.280840
      THO=TH*.000578176
      VO=V*.00671?6897
      PRINT 101,PO,DO,TO,HO,SO,CPPO,CVVO,WO,THO,VO
 101  FORMAT(* PRESSURE=*,F10.3,* LB/SQ IN, DENSITy?*,F10.4,* LB/CU FT*
     1/* TEMPERATURE=*,F8.2,* F, ENTHALPY=*,F9.2,* BTU/LB*
     2/* ENTROPY=*,F6.2,* BTU/LB-F*
     3/* CP=*,F7.3,* AND CV=*,F7.3,* BTU/LB-F*
     4/* SPEED OF SOUND=*,F8.1,* FT/SEC*
     5/* THERMAL CONDUCTIVITY=*,F7.2,* BTU/FT-HR-F*
     6/* VISCOSITY=*,F7.2,* LB/FT-S X E+7*)
      GO TO 18
  15  IF(P.LE.0.0.AND.T.LE.0.0)GO TO 21
      IF(P.GT.0.0)GO TO 20
      IF(T.GT.TC.OR.T.LT.TTP)GO TO 22
      P=VPNHE(T)
      PRINT 109
      READ *,IP
      IF(IP.GT.0)P=P-.0001
      IF (IP.GE.1)P=P+.00001
 109  FORMAT(* DO YOU WANT SATURATED LIQUID OR VAPOR*
     1/* ENTER A 1 FOR VAPOR OR A 0 FOR LIQUID*)
      GO TO 131
  20  IF(P.GT.PC)GO TO 22
      T=VPTEHE(P)
```

```
      PRINT 109
      READ *,IP
      IF(IP.GT.0)P=P-.0001
      IF (IP.GE.1)P=P+.00001
      GO TO 131
   22 PRINT 107
  107 FORMAT(* YOUR INPUT PRESSURE OR TEMPERATURE IS OUT OF RANGE*
     1/* OF THE SATURATION CURVE, TC=5.201, PC=2.275, T TRIPLE=2.177*
     2/* TRY AGAIN*)
      GO TO 17
   21 RETURN
   25 PRINT 108
  108 FORMAT(* YOUR INPUT TEMPERATURE OR PRESSURE IS OUT OF RANGE*
     1/* TEMP MUST BE BETWEEN 2.177 AND 1500K AND PRESSURE BETWEEN*
     2/* 0 AND 1000BAR, TRY AGAIN*)
      GO TO 17
      END
      SUBROUTINE INFO
      PRINT 2
    2 FORMAT(* WHEN THE PROGRAM ASKS FOR A FLUID SELECTION, ENTER THE AP
     1PROPRIATE NUMBER*
     2/* AN INAPPROPRIATE NUMBER WILL TERMINATE THE PROGRAM*)
      PRINT 1
    1 FORMAT(*  WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY, AND*/*  T
     1EMPERATURE, ENTER ANY 2 OF THE THREE AND A 0 FOR THE THIRD.*/*  TH
     2E ORDER MUST BE P, D,T, AND ONE OF THE THREE MUST BE 0. *
     3/* IF ALL THREE ARE 0 THE PROGRAM ASKS FOR A NEW FLUID*)
      PRINT 110
  110 FORMAT(* IF YOU ARE INTERESTED IN A DEFINITION OF THE VARIOUS*
     1/* MODIFICATIONS OF HYDROGEN ENTER A 1, IF NOT ENTER A 0*)
      READ *,IC
      IF(IC.NE.1)GO TO 111
      CALL H2 INFO
  111 PRINT 112
  112 FORMAT(* IF YOU ARE INTERESTED IN THE SOURCES OF THESE PROGRAMS*
     1/* ENTER A 1 IF NOT ENTER A 0*)
      READ *,IS
      IF(IS.EQ.1)CALL SOURCE
      RETURN
      END
      SUBROUTINE H2 INFO
      PRINT 100
  100 FORMAT(* THE HYDROGEN MOLECULE IS MADE UP OF TWO HYDROGEN ATOMS*
     1/* THERE ARE TWO POSSIBLE RELATIVE ORIENTATIONS OF THE NUCLEAR*
     2/* SPIN OF THE ATOMS IN A MOLECULE OF HYDROGEN. I.E. THE SPINS*
     3/* MAY BE IN THE SAME DIRECTION (ORTHO) OR IN OPPOSITE DIRECTIONS*
     4/* (PARA).  THE RELATIVE AMOUNTS OF ORTHO AND PARA HYDROGEN IN*
     5/* A SAMPLE OF EQUILIBRIUM HYDROGEN IS TEMPERATURE DEPENDANT*)
      PRINT 101
  101 FORMAT(* AT ROOM TEMPERATURE EQUILIBRIUM HYDROGEN IS 75 PERCENT*
     1/* ORTHO AND 25 PERCENT PARA AND IS CALLED NORMAL HYDROGEN*
     2/* AT 20 KELVIN EQUILIBRIUM HYDROGEN IS 99.8 PERCENT PARA.*)
      RETURN
      END
      SUBROUTINE SOURCE
      PRINT 100
  100 FORMAT(* THIS PROGRAM WAS WRITTEN BY R.D. MCCARTY AT THE NATIONAL*
     1/* BUREAU OF STANDARDS IN BOULDER COLORADO UNDER A CONTRACT WITH*
     2/* THE JOHNSON SPACE CENTER IN HOUSTON TEXAS.  THE NASA CONTRACT*
     3/* MONITOR AT JSC IS WALTER SCOTT.  THE DOCUMENTATION OF THE*
     4/* PROGRAM IS IN PREPARATION AND IS PLANNED AS A JOINT*
     5/* NASA-NBS PUBLICATION*)
```

```
      RETURN
      END
      FUNCTION FNDDHE(PI,TI)
C SOLVES THE HELIUM EQUATION OF STATE FOR DENSITY IN MOL/LITER
C  GIVEN A PRESSURE IN ATMOSPHERES AND A TEMPERATURE IN DEGREES K
      T=TI
      P=PI
      IF(T.LT.5.2)GO TO 6
      PM=1001.
      IF(T.LT.15.)PM=PMELT(T)
      IF(PM.LT.P)GO TO 30
      IF(T.GT.100.)GO TO 1
      PC=2.2449+(T-5.2014)*1.76
      IF(P.LT.PC)GO TO 1
      PM=200.+(T-5.2)*12.31
      D=17.399+((PM-PC)/(PM-PC+1.))*2.33*17.399
      GO TO 7
    2 D=.0001
      IF(T.LT.4.2)GO TO 7
    1 VB=VIRB(T)
      RT=0.0820558*T
      P1=RT/P
      D=1./(P1+VB)
      GO TO 7
    6 IF(P.LT.VPNHE(T))GO TO 2
      DS=46.18+(T-2.)*4.02
      DL=DSATL(T)*1000./4.0026
      DEL=DS-DL
      PM=PMELT(T)
      IF(P.GT.PM)GO TO 30
      D=DL+DEL*P/PM
    7 DO 10 I=1,50
      P2=FNDPHE(D,T)
      IF(ABS(P-P2)-1.E-7*P)20,20,8
    8 DP=DPDDHE(D,T)
      CORR=(P2-P)/DP
      IF(ABS(CORR)-1.E-7*D)20,20,10
   10 D=D-CORR
      FNDDHE=0
      RETURN
   20 FNDDHE=D
      RETURN
   30 FNDDHE=0
      RETURN
      END
      FUNCTION FNDPHE(DD,TT)
C THE MAIN EQUATION OF STATE ROUTINE FOR HELIUM:
C THE INPUT IS DENSITY IN MOLES/LITER AND TEMPERATURE
C IN DEGREES K, THE OUTPUT IS PRESSURE,DP/DD,DP/DT,ENTHALPY,
C ENTROPY AND CV IN ATMOSPHERES AND JOULES
      DIMENSION A(26),B(27,4)
      COMMON/IDEX/ID
      DATA(ID=0)
      DATA((B(I),I=82,108)=
     1        5.988310109E-9,-4.9653052187E-7,-3.8116033499E-6,3.68116713
     13E-5,-1.4830691828E-4,3.0596174335E-4,-3.3908190224E-4,1.962408024
     22E-4,1.5527899712E-5,-3.6110403503E-5,-1.0839788073E-5,4.972810121
     37E-5,1.938145109E-5,-4.149640896E-4,-5.7465772899E-4,-4.3470945634
     4E-3,-6.8383888924E-2,-2.1382474225E-2,2.7106954908E-2,-1.262796778
     58E-2,2.587575338E-3,7.9041608815E-2,-1.4024724318E-4,-2.8278987249
     6E-7,1.7336410358E-6,-2.5454187855E-6,-0.0005)
      DATA((B(I),I=55,81)=-1.4802195348E-8,4.1721791119E-7,-2.3326553271
```

```
      1E-7,4.085511088E-7,1.0900567964E-5,-5.0060952775E-5,1.1312765043
      2E-4,-1.2539843287E-4,1.9661380688E-6,1.7122932666E-4,2.3051000563
      3E-4,-9.65647391E-4,-3.6027 735292E-5,1.6079946555E-3,-2.7441763615
      4E-2,.14739506957,-.43559344838,1.3447956078,-1.7040375125,.9026267
      54040,5.6875644111E-3,-1.4438146625E-1,3.3768874851E-3,1.0754201218
      6E-6,-4.5264622308E-5,3.8597388864E-5,-.0005)
       DATA((B(I),I=28,54)=-4.2287454626E-8,4.4529354413E-7,-1.0246150954
      1E-5,8.5254608956E-5,-2.5163069255E-4,3.2877709285E-4,-1.060195758
      2E-4,-1.0687738074E-4,-3.2120950632E-5,1.415901897E-4,1.4725630701
      4E-3,-2.618354941E-3,2.0461501117E-5,1.2746996288E-3,-2.0272929583
      5E-2,7.4648036615E-2,-.17217966521,.51053439738,-.40178202697,
      6.26829864632,7.906601204E-3,-8.9393485656E-2,-.15076580053,
      72.6882494327E-6,-3.3794316835E-5,-2.4495951195E-5, -.0005)
       DATA((B(I),I=1,27)=
      A        -1.5096862619E-7,6.4640898904E-7,4.1362357367E-5,
      1-3.7910190353E-4,1.3806454049E-3,-2.5085412058E-3,2.3697560398E-3
      2,-9.5726461066E-4,3.7405931828E-5,-6.4103220333E-4,
      31.8579366177E-3,7.4007986606E-4,1.4792568148E-4,-3.2531355477E-3,
      41.9518739286E-2,-.10571817135,.33164944449,-.51130022535,
      53.9940004906E-1,-.15555244471,4.906264031E-3,-2.6148004377E-2,
      63.4221685545E-2,5.4159662622E-6,-1.0687806777E-5,-8.9484651869E-6,
      7-.0025)
       KP=1
       GO TO 10
       ENTRY DPDTHE
       KP=2
       GO TO 10
       ENTRY DPDD HE
       KP=3
       GO TO 10
       ENTRY ENTRHE
       KP=4
       GO TO 10
       ENTRY ENTHHE
       KP=5
       GO TO 10
       ENTRY CVHE
       KP=6
   10  K1=0
       KH=1
       K=1
       KK=1
       K4=1
       IF(ID.NE.0)GO TO 20
       IF(TT.GE.15.)GO TO 20
       IF(TT.GT.10)GO TO 30
       IF(DD.GT.17.3987)GO TO 40
   11  I=1
       T=TT
       D=DD
    8  GO TO (9,100,200,300,400,500)KP
    9  D2=D*D
       D3=D2*D
       D4=D3*D
       D5=D4*D
       GAMMA=B(27,I)
       EX=EXP(D2*GAMMA)
       EXD3=EX*D3
       EXD5=EX*D5
       M=I
       N=1
       A(N)=D5*D   $   N=N+1
```

```
      A(N)=A(N-1)/T  $  N=N+1
      DO 2 I=1,6
      FI=I
      A(N)=D5*T**(.75-FI/4.)
    2 N=N+1
      DO 3 I=1,4
      FI=I
      A(N)=D4*T**(1.5-FI)
    3 N=N+1
      DO 1 I=1,8
      FI=I
      A(N)=D3*T**(1.5-FI/2.)
      N=N+1
    1 CONTINUE
      DO 4 I=1,3
      FI=I
      A(N)=EXD3*T**(1.-FI)
    4 N=N+1
      DO 5 I=1,3
      FI=I
      A(N)=EXD5*T**(1.-FI)
    5 N=N+1
      N=N-1
      I=M
    7 P=0
      DO 15 J=1,N
   15 P=P+B(J,I)*A(J)
      P=P+.0820558*D*T*(1.+VIRB(T)*D)
      IF(KH.LT.1)GO TO 413
      GO TO(50,50,30,40)K
  100 D2=D*D
      D3=D**3
      D4=D3*D
      D5=D4*D
      D6=D5*D
      T2=T*T
      T3=T2*T
      T4=T**4
      M=I
      GAMMA=B(27,M)
      EX=EXP(D2*GAMMA)
      N=1
      R=.0820558
      A(N)=0.0   $  N=N+1
      A(N)=(-1.)*D6/T2  $  N=N+1
      DO 102 I=1,6
      FI=I
      A(N)=D5*T**(.75-FI/4.-1.)*(.75-FI/4.)
  102 N=N+1
      DO 103 I=1,4
      FI=I
      A(N)=D4*T**(1.5-FI/1.-1.)*(1.5-FI)
  103 N=N+1
      DO 101 I=1,8
      FI=I
      A(N)=D3*T**(1.5-FI/2.-1.)*(1.5-FI/2.)
  101 N=N+1
      DO 104 I=1,3
      FI=I
      A(N)=EX*D3*T**(1.-FI-1.)*(1.-FI)
  104 N=N+1
      DO 105 I=1,3
```

```
      FI=I
      A(N)=EX*D5*T**(1.-FI-1.)*(1.-FI)
  105 N=N+1
      N=N-1
      P=0
      DO 115 J=1,N
  115 P=P+A(J)*B(J,M)
      P=P+R*D*(1.+VIRB(T)*D)+R*D*T*DBDT(T)*D
      I=M
      GO TO(50,50,30,40)K
  200 D2=D*D
      D3=D2*D
      D4=D3*D
      D5=D4*D
      M=I
      GAMMA=B(27,M)
      EX=EXP(D2*GAMMA)
      DEX=GAMMA*2.*D*EX
      N=1
      R=0.0820558
      A(N)=6.*D5  $  N=N+1
      A(N)=A(N-1)/T  $  N=N+1
      DO 202 I=1,6
      FI=I
      A(N)=5.*D4*T**(.75-FI/4.)
  202 N=N+1
      DO 203 I=1,4
      FI=I
      A(N)=D3*4.*T**(1.5-FI)
  203 N=N+1
      DO 201 I=1,8
      FI=I
      A(N)=D2*3.*T**(1.5-FI/2.)
  201 N=N+1
      DO 204 I=1,3
      FI=I
      A(N)=(DEX*D3+3.*D2*EX)*T**(1.-FI)
  204 N=N+1
      DO 205 I=1,3
      FI=I
      A(N)=(DEX*D5+5.*D4*EX)*T**(1.-FI)
  205 N=N+1
      N=N-1
      P=0
      DO 215 J=1,N
  215 P=P+A(J)*B(J,M)
      I=M
      P=P+R*T*(1.+2.*D*VIRB(T))
      GO TO(50,50,30,40)K
  300 D2=D*D
      D3=D2*D
      D4=D3*D
      N=1
      R=.0820558
      M=I
      GAMMA=B(27,M)
      EX=EXP(D2*GAMMA)
      A(N)=0.0      $ N=N+1
      A(N)=(D4*D/5.)*T**(-2.)*(-1.)  $  N=N+1
      DO 302 I=1,6
      FI=I
      A(N)=(D4/4.)*T**(.75-FI/4.-1.)*(.75-FI/4.)
```

```
302 N=N+1
    DO 303 I=1,4
    FI=I
    A(N)=(D3/3.)* T**(1.5-FI-1.)*(1.5-FI)
303 N=N+1
    DO 301 I=1,8
    FI=I
    A(N)=(D2/2.)*T**(1.5-FI/2.-1.)*(1.5-FI/2.)
301 N=N+1
    DO 304 I=1,3
    FI=I
    A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)
304 N=N+1
    DO 305 I=1,3
    FI=I
    A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
   1T**(1.-FI-1.)*(1.-FI)
305 N=N+1
    N=N-1
    SINT=D*R*(VIRB(T)+T*DBDT(T))
    DO 306 I=1,N
306 SINT=SINT+B(I,M)*A(I)
    N=21
    EX=1.
    D2=0
    DO 310 I=1,3
    FI=I
    A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)
310 N=N+1
    DO 311 I=1,3
    FI=I
    A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
   1T**(1.-FI-1.)*(1.-FI)
311 N=N+1
    N=N-1
    DO 312 I=21,N
312 SINT=SINT-B(I,M)*A(I)
    P=(9.371658+5.193043*ALOG(T/4.2144)-25.31469*(SINT+R*ALOG(R*T*D)))
    P=P*4.0026
    I=M
    GO TO(50,50,30,40)K
400 KH=0
    GO TO 9
413 PP=P
    KH=1
    D2=D*D
    D3=D*D2
    D4=D3*D
    N=1
    R=.0820558
    M=I
    GAMMA=B(27,M)
    EX=EXP(D2*GAMMA)
    A(N)=(D4*D)/5.    $   N=N+1
    A(N)=(D4*D/5.)*(2./T)       $   N=N+1
    DO 402 I=1,6
    FI=I
    A(N)=(D4/4.)*(T**(.75-FI/4.)-T**(.75-FI/4.)*(.75-FI/4.))
402 N=N+1
    DO 403 I=1,4
    FI=I
    A(N)=(D3/3.)*(T**(1.5-FI)-T**(1.5-FI)*(1.5-FI))
```

```
403 N=N+1
    DO 401 I=1,8
    FI=I
    A(N)=(D2/2.)*(T**(1.5-FI/2.)-T**(1.5-FI/2.)*(1.5-FI/2.))
401 N=N+1
    DO 404 I=1,3
    FI=I
    A(N)=(EX/(2.*GAMMA))*(T**(1.-FI)-T**(1.-FI)*(1.-FI))
404 N=N+1
    DO 405 I=1,3
    FI=I
    A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*(T**(1.-FI)-T**(1.-FI)
   1*(1.-FI))
405 N=N+1
    N=N-1
    HINT=R*T*T*D*DBDT(T)  *(-1.)
    DO 406 I=1,N
406 HINT=HINT+B(I,M)*A(I)
    N=21
    D2=0
    EX=1.
    DO 410 I=1,3
    FI=I
    A(N)=(EX/(2.*GAMMA))*(T**(1.-FI)-T**(1.-FI)*(1.-FI))
410 N=N+1
    DO 411 I=1,3
    FI=I
    A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*(T**(1.-FI)-T**(1.-FI)
   1*(1.-FI))
411 N=N+1
    N=N-1
    DO 412 I=21,N
412 HINT=HINT-B(I,M)*A(I)
    P=21.82282+5.193043*(T-4.2144)+25.31469*(HINT+PP/D-R*T)
    P=P*4.0026
    I=M
    GO TO(50,50,30,40)K
500 D2=D*D
    D3=D2*D
    D4=D3*D
    N=1
    R=.0820558
    M=I
    GAMMA=B(27,M)
    EX=EXP(D2*GAMMA)
    SINT=T*D*R*(2.*DBDT(T  )+D2DBDT2(T)*T)
    A(N)=0.0  $  N=N+1
    A(N)=(D4*D/5.)*T**(-2.)*(-1.)*(-2.)  $  N=N+1
    DO 502 I=1,6
    FI=I
    A(N)=(D4/4.)*T**(.75-FI/4.-1.)*(.75-FI/4.)*(.75-FI/4.-1.)
502 N=N+1
    DO 503 I=1,4
    FI=I
    A(N)=(D3/3.)* T**(1.5-FI-1.)*(1.5-FI)*(1.5-FI-1.)
503 N=N+1
    DO 501 I=1,8
    FI=I
    A(N)=(D2/2.)*T**(1.5-FI/2.-1.)*(1.5-FI/2.)*(1.5-FI/2.-1.)
501 N=N+1
    DO 504 I=1,3
    FI=I
```

```
      A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
  504 N=N+1
      DO 505 I=1,3
      FI=I
      A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
     1T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
  505 N=N+1
      N=N-1
      DO 506 I=1,N
  506 SINT=SINT+B(I,M)*A(I)
      P=SINT
      EX=1.
      D2=0
      N=21
      DO 510 I=1,3
      FI=I
      A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
  510 N=N+1
      DO 511 I=1,3
      FI=I
      A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
     1T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
  511 N=N+1
      N=N-1
      DO 512 I=21,N
  512 P=P-B(I,M)*A(I)
      P=5.193043*(3./5.)*4.0026-P*101.3278
      I=M
      GO TO(50,50,30,40)K
   20 K=2
      I=3
      IF(ID.NE.0)I=4
      T=TT
      D=DD
      GO TO 8
   30 K=3
      GO TO(33,34,35)KK
   33 D=DD
      T=TT
      KK=2
      IF(DD.GT.17.3987)GO TO 40
      I=1
      GO TO 8
   34 PTI=P
      I=3
      KK=3
      T=TT
      D=DD
      GO TO 8
   35 PTIII=P
   38 F=(15.-T)/5.
             P=F*PTI+(1.-F)*PTIII
      IF(KH.LT.1)GO TO 413
      FNDPHE=P
      RETURN
   40 IF(K.EQ.3)K1=3
      GO TO(41,42,43,44)K4
   41 K=4
      I=2
      K4=2
      D=DD
      IF(K1.EQ.0)T=TT
      GO TO 8
```

```
   42 PIID=P
      D=17.3987
      IF(T.LT.5.2014)D=DSATL(T)*1000./4.0026
      K4=3
      GO TO 8
   43 PIIDC=P
      I=1
      K4=4
      GO TO 8
   44 PIDC=P
      P=PIDC+(PIID-PIIDC)
      K4=1
      IF(K1.EQ.3)GO TO 30
      FNDPHE=P
   50 FNDPHE=P
      RETURN
      END
      FUNCTION CPHE(D,T)
C CSINH(P)
C FOR HELIUM, INPUT IS DENSITY (MOLES/LITER) AND TEMPERATURE(K)
C OUTPUT IS  JOULES/MOL-K
C(SEE ALSO NEXT PAGE)
      P=CVHE(D,T)+(T*(DPDTHE(D,T)**2)/((D**2)*DPDDHE(D,T)))*101.325
      CPHE=P
      END
      FUNCTION SOUNHE(D,T)
C VELOCITY OF SOUND FOR HELIUM, INPUT IS DENSITY (MOLES/LITER)
C AND TEMPERATURE (KELVIN),OUTPUT IS IN METRES/SEC
      S=((CPHE(D,T)/CVHE(D,T))*(DPDDHE(D,T)*25311.))**.5
      SOUNHE=S
      END
      FUNCTION VIRB(T)
      DIMENSION A(9),V(45)
      DATA(A=-5.0815710041E-7,-1.1168680862E-4,1.1652480354E-2,
     1 7.4474587998E-2,-5.3143174768E-1,-9.5759219306E-1,
     2 3.9374414843,-5.1370239224,2.0804456338)
C     COEFFICIENTS FROM PROGRAM 5/28/70-1630
C     THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C     HELIUM.  THE RANGE IS FROM 2 TO 1500 DEG K.  INPUT IS TEMPERATURE
C     IN DEGREES KELVIN AND IUSE, IF ISUE IS 0 OR NEGATIVE THE ROUTINE
C     CALCULATES B FOR THE EQUATION PV=RT(1+BD+..., FOR OTHER VALUES OF
C     IUSE, THE ROUTINE CALCULATES THE VARIANC OF B AT THE INPUT TEMP
C     UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,4/3/69-1253,R.D.MCCARTY
C     REVISED 2/12/70-925
    1 B=0
      DO 5 I=1,9
      FI=I
    5 B=B+T**(1.5-FI/2.)*A(I)
      VIRB=B
      RETURN
      END
      FUNCTION DBDT (T)
      DIMENSION A(9),V(45)
C     THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C     HELIUM.  THE RANGE IS FROM 2 TO 1500 DEG K.  INPUT IS TEMPERATURE
C     IN DEGREES KELVIN AND IUSE, IF ISUE IS 0 OR NEGATIVE THE ROUTINE
C     CALCULATES B FOR THE EQUATION PV=RT(1+BD+..., FOR OTHER VALUES OF
C     IUSE, THE ROUTINE CALCULATES THE VARIANC OF B AT THE INPUT TEMP
      DATA(A=-5.0815710041E-7,-1.1168680862E-4,1.1652480354E-2,
     1 7.4474587998E-2,-5.3143174768E-1,-9.5759219306E-1,
     2 3.9374414843,-5.1370239224,2.0804456338)
C     UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,5/28/70-1630,R.D.MCCARTY
```

```
    1 B=0
      DO 5 I=1,9
      FI=I
    5 B=B+T**(.5-FI/2.)*A(I)*(1.5-FI/2.)
      DBDT=B
      RETURN
      END
      FUNCTION D2DBDT2(T)
      DIMENSION A(9)
      DATA(A=-5.0815710041E-7,-1.1168680862E-4,1.1652480354E-2,
     1 7.4474587998E-2,-5.3143174768E-1,-9.5759219306E-1,
     2 3.9374414843,-5.1370239224,2.0804456338)
C     THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C     HELIUM.  THE RANGE IS FROM 2 TO 1500 DEG K.  INPUT IS TEMPERATURE
C     IN DEGREES KELVIN AND IUSE, IF ISUE IS 0 OR NEGATIVE THE ROUTINE
C     CALCULATES B FOR THE EQUATION PV=RT(1+BD+...), FOR OTHER VALUES OF
C     IUSE, THE ROUTINE CALCULATES THE VARIANC OF B AT THE INPUT TEMP
C     UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,5/28/70-1630,R.D.MCCARTY
    1 B=0
      DO 5 I=1,9
      FI=I
    5 B=B+T**(.5-FI/2.-1.)*(1.5-FI/2.)*(.5-FI/2.)*A(I)
      D2DBDT2=B
      RETURN
      END
      FUNCTION VPNHE(TT)
C     GIVES A VAPOR PRESSURE FOR HELIUM IN ATMOSPHERES GIVEN A
C     TEMPERATURE IN KELVIN.  THE FUNCTION REPRODUCES THE 1968 HELIUM
C     TEMPERATURE SCALE TO .0001 KELVIN
      DIMENSION C(12),D(14)
      DATA(C=-3.9394635287,141.27497598,-1640.7741565,11974.557102,
     1-55283.309818,166219.56504,-325212.82840,398843.22750,
     2-277718.06992,83395.204183)
      DATA(D=-49.510540356,651.9236417,-3707.5430856,12880.673491,
     1 -30048.545554,49532.267436,-59337.558548,52311.296025,
     2-33950.233134,16028.674003,-5354.1038967,1199.0301906,
     3 -161.46362959,9.8811553386)
      T=TT
      T=T-DELT(T)
      P=0
      IF(T-2.1720)10,10,1
    1 DO 5 I=1,10
    5 P=P+C(I)*T**(2-I)
      VP =EXP(P)/.76E+6
      VPNHE=VP
      RETURN
   10 DO 15 I=1,14
   15 P=P+D(I)*T**(2-I)
      VP =EXP(P)/.76E+6
      VPNHE=VP
      RETURN
      END
      FUNCTION DELT(TT)
C ADJUSTS THE TEMPERATURE TO A NEW SCALE
      T=TT
      DELT=.001+.002*T
      RETURN
      END
      FUNCTION VPTEHE(PP)
C     SOLVES THE VAPOR PRESSURE EQUATION FOR TEMPERATURE GIVEN A PRESSURE
C     THE FLUID IS HELIUM AND THE UNITS ARE ATMOSPHERES AND KELVINS
      P=PP
```

```
      IF(P.LT..842105)GO TO 12
      T=5.0
      PCAL=VPNHE(T)
      GO TO 13
   12 PCAL=.049737
      IF(ABS(P-PCAL)-.0000001*PP)11,11,1
    1 T=2.1720
   13 DO 10 I=1,26
      DP=DVPNHE(T)
      DEL=(PCAL-P)/DP
      T=T-DEL
      PCAL=VPNHE(T)
      IF(ABS(P-PCAL)-.0000001*P)11,11,2
    2 IF(ABS(DEL)-.0000001*T)11,11,10
   10 CONTINUE
      PRINT 100,T
   11 VPTEHE=T
      RETURN
  100 FORMAT(* TEMPERATURE ITTERATION FAILED AT T=*,E14.7)
      END
      FUNCTION DVPNHE(TT)
C     GIVES THE DERIVATIVE OF THE VAPOR PRESSURE FOR HELIUM GIVEN A
C     TEMPERATURE IN KELVIN9  PRESSURE IS IN ATMOSPHERES
      DIMENSION C(12),D(14)
      DATA(C=-3.9394635287,141.27497598,-1640.7741565,11974.557102,
     1-55283.309818,166219.56504,-325212.82840,398843.22750,
     2-277718.06992,83395.204183)
      DATA(D=-49.510540356,651.9236417,-3707.5430856,12880.673491,
     1 -30048.545554,49532.267436,-59337.558548,52311.296025,
     2-33950.233134,16028.674003,-5354.1038967,1199.0301906,
     3 -161.46362959,9.8811553386)
      P=0
      T=TT-DELT(TT)
      IF(T-2.1720)10,10,1
    1 DO 5 I=1,10
    5 P=P+C(I)*T**(1-I)*(2-I)
      DVPNHE=P*VPNHE(T)
      RETURN
   10 DO 15 I=1,14
   15 P=P+D(I)*T**(1-I)*(2-I)
      DVPNHE=P*VPNHE(T)
      RETURN
      END
      FUNCTION  TRANSP(DD,TT)
C      HELIUM
C     THIS ROUTINE CALCULTATES THERMAL CONDUCTIVITY AND VISCOSITY
C     FOR AN INPUT OF DEGREES KELVIN AND DENSITY IN MOLES PER LITER
C     THE RANGE OF TEMPERATURE IS FROM 2 TO 2000 K
C     FOR TEMPERATURES BELOW 300 K FORMULAS OFD VINCE ARP AND GE STEWARD
C     ARE USED, FOR TEMPERATURES ABOVE 300 THE DILUTE GAS OF A CRITICAL
C     COMPILATION FROM ENGLAND IS USED FOR BOTH VISCOSITY AND
C     THERMAL CONDUCTIVITY AND THE EXCESS FUNCTIONS FROM THE ROUTINES BY
C     ARP AND STEWART)   THE EXCESS FUNCTIONS ARE CALCULATED FOR TEMPS
C     ABOVE 300 K WITH THE TEMPERATURE DEPENDENCE HELD AT 300 K
C     FOR TEMPS BELOW 300 K TO 100 K THE VISCOSITY EXCESS IS CALC
C     FROM STEWARTS ROUTINE BUT THE DILUTE GAS VALUES ARE TAKEN FROM
C     THE ENGLISH CORRELATION FOR TEMPS BETWEEN 100 AND    110 T
C     DILUTE GAS  CALCULATION IS AVARAGED
      ENTRY THERHE
    1 D=DD
      T=TT
      RHO=D*4.0026E-3
```

```
      IF(T.LT.300.)GO TO 5
      THO30=VISCX(300.)*.00781736
      THO300=CONZ(300.)
      DEL300=DELC(300.,RHO)
      THO=VISCX(T)*.00781736+THO300-THO30
      THE=THO300*DEL300-THO300
      TRANSF=THO+THE
      RETURN
    5 TRANSF=CONZ(T)*DELC(T,RHO)+CRITIC(T,RHO)
C     OUTPUT IN MW/CM.K
      RETURN
      ENTRY VISCHE
      D=DD
      T=TT
      IF(T.LT.100.)GO TO 10
      IF(T.LT.300.)GO TO 8
      ETAO=VISCX(T)
      ETO30=VISCX(300.)
      ETO300=VISCDT(0.0,300.)
      ETE300=VISCDT(D,300.)-ETO300
      TRANSF=ETAO+ETE300
C  OUTPUT UNITS ARE MICROPOISE
      RETURN
    8 IF(T.LT.110.)GO TO 9
      ETAO=VISCX(T)
      ETEB=VISCDT(D,T)-VISCDT(0.0,T)
      TRANSF=ETAO+ETEB
      RETURN
    9 ETA1=VISCDT(0.0,100.)
      ETA2=VISCX(110.)
      ETAO=ETA1+(ETA2-ETA1)*(T-100.)/10.
      TRANSF=ETAO+VISCDT(D,T)-VISCDT(0.0,T)
      RETURN
   10 TRANSF=VISCDT(D,T)
      RETURN
      END
      FUNCTION VISCX( T )
C CALCULATES THE DILUTE GAS VISCOSITY FOR HELIUM
C FOR TEMPERATURES FROM 110K TO 300K
      VISCX = 196. * T ** 0.71938 * EXP( 12.451 / T - 295.67 / T / T -
     A    4.1249 )
      RETURN
      END
      FUNCTION DELC(TEMP, RHO)
C CALCULATE THE EXCESS THERMAL CONDUCTIVITY FOR HELIUM, INPUT IS
C  TEMPERATURE(K) AND DENSITY(MOLES/LITER) OF HELIUM
C     K=KZERO*EXPF(B(T)*RHO + C(T)*RHO**2)
C      THIS PROGRAM RETURNS EXPF(B(T)*RHO + C(T)*RHO**2)
    1 BB=ALOG(TEMP)    $     CC=1.0/TEMP
      BETTY = 4.7470660612 - 5.3641468153*BB + 3.4639703698*BB**2
     2 -1.0702455443*BB**3 + 0.1571349306*BB**4 -0.00892140047*BB**5
      B=EXP(BETTY)
      C = 2.2109006708 + 187.74174808*CC - 1281.0947055*CC*CC
     3 +3645.2393216*CC**3 - 3986.6937948*CC**4
      DELC=EXP(B*RHO+C*RHO*RHO)
      RETURN
      END
      FUNCTION CONZ(TEMP)
C     KZERO IN MILLIWATTS/CM-K, T IN KELVIN9  22 JUNE 71.
    1 ANNE=ALOG(TEMP)
      FAT = -4.3611622157 + 1.9250159286*ANNE - 0.52544120165*ANNE**2
     1+ 0.090045763885*ANNE**3  -  0.0054773874708*ANNE**4
```

```
      CONZ=EXP(PAT)
      RETURN
      END
      FUNCTION VISCDT(DGC,T)
C     W.G.STEWARD,S DATA   23 JUNE 71
C  INPUT UNITS ARE KELVIN AND MOL/LITER
C  OUTPUT UNITS ARE MICROPOISE
      TL=ALOG(T)     $     R=DGC*4.0026/1000.
      ANNE= -0.135311743/TL + 1.00347841  +  1.20654649*TL
     1 -0.149564551*TL*TL+0.0125208416*TL**3
      BETTY=R*(-47.5295259/TL + 87.6799309  -42.0741589*TL
     1+8.33128289*TL*TL -0.589252385*TL**3)
      CAROL = R*R*(547.309267/TL - 904.870586 + 431.404928*TL
     1-81.4504854*TL*TL + 5.37008433*TL**3)
      DAGMAR=R**3*(-1684.39324/TL  +  3331.08630  -  1632.19172*TL
     1+308.804413*TL*TL  -  20.2936367*TL**3)
      VISCDT=EXP(ANNE+ BETTY+ CAROL+ DAGMAR)
      RETURN
      END
      FUNCTION CRITIC(TEMP,RHO)
C     CRITICAL ANOMALY FOR HE THERM. CON., SCALED FROM H-2
C     T IN KELVIN, REQUIRES DENSITY IN GRAMS/CC AND CP IN JOULES/MOLE
C     THIS DECK OF 18 SEPT 70, I HAVE USED MCCARTY'S HE DECKS OF 7/18/70
    4 T=TEMP
    5 DML=RHO/0.0040026
    6 IF(T .GE. 11.83) GO TO 11
      IF(RHO.GT.0.12) GO TO 11
    7 CP1=CPHE(DML,T)
    8 CP2=CPHE(DML,11.83)
    9 CRITIC=0.0026*(CP1-CP2)/4.0026
   10 IF(CRITIC)11,12,12
   11 CRITIC=0.0
   12 RETURN
      END
      FUNCTION DSATV(TT)
C CALCULATES THE SATURATED LIQUID AND VAPOR DENSITIES FOR HELIUM,
C INPUT IS TEMPERATURE(K) OUTPUT IS GM/CC (SEE NEXT PAGE)
      DIMENSION GV(6),GL(6)
      DATA(GL=.12874326484,-.43128217346,1.7851911824,-3.3509624489,
     1  3.0344215824,-1.0981289602)
      DATA(GV=-.069267495322,-.12925325553,.29347470712,-.40806658212,
     1  .35809505624,-.11315580397)
      DATA(DC=.06964)
      DATA(TC=5.2014)
      T=TT
      DCAL=DC
      R=(1.-T/TC)
      DO 1 I=1,6
      FI=I
    1 DCAL=DCAL+GV(I)*R**(FI/3.)
      DSATV=DCAL
      RETURN
      ENTRY DSATL
      T=TT
      DCAL=DC
      R=(1.-T/TC)
      DO 2 I=1,6
      FI=I
    2 DCAL=DCAL+GL(I)*R**(FI/3.)
      DSATV=DCAL
      RETURN
      END
```

```
      FUNCTION P MELT(TT)
C CALCULATE THE MELTING PRESSURE FOR HELIUM, INPUT IS TEMP K,
C OUTPUT IS PRESSURE IN ATMOSPHERES
      DIMENSION A(5)
      DATA(A=33.28,-44.156,31.799 ,-4.8159,0.30313)
      T=TT
      IF(T.LE.5.2)GO TO 7
      PMELT=-17.80+17.31457*T**1.555414
      PMELT=PMELT*.98066/1.01325
      RETURN
    7 P=0.0
      DO 9 I=1,5
    9 P=P+A(I)*T**(I-1)
      PMELT=P*9.80665/10.1325
      RETURN
      END
      FUNCTION FNDPNE(D,T)
C  CALCULATES THE PRESSURE IN ATMOSPHERES FOR NEON,
C USES DENSITY (MOL/LITER) AND TEMPERATURE OF NEON AS INPUT
    1 FNDPNE=PC(D,T)
      RETURN
      END
      FUNCTION ENTHA(P,D,T)
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      D1=D
      D2=D**2
      D3=D2*D
      D4=D3*D
      D5=D4*D
      T1=T
      T2=T*T
      T3=T2*T
      T4=T3*T
      EX=EXP(A19*D2)
      EXI1=(EX-1.)/(2.*A19)
      EXI3=EX*D*D/(2.*A19)-(EX-1.)/(2.*A19**2)
      ENTHA =P/D-A1*T+A4*D3/3.+A5*D4/(T1*2.)
     1-A6*D2*T2/2.+A9*D2/T1+3.*A10*D2/(T2*2.)
     2+A12*D1+2.*A13*D1/T1+3.*A14*D1/T2
     3+3.*A15*EXI1/T2+4.*A16*EXI1/T3
     4+3.*A17*EXI3/T2+4.*A18*EXI3/T3
     6+A2*D5/5.+A8*D2/2.
C     CALCULATES ENTHALPY CHANGE FROM 0 TO FINITE DENSITIES ALONG
C     ISOTHERM ACCORDING TO DTRI4
C FOR NEON INPUT IS PRESSURE IN ATMOSPHERES,DENSITY IN MOLES/LITER
C AND TEMPERATURE IN K,OUTPUT IS JOULES PER MOLE.
      RETURN
      END
      FUNCTION DLIQNE(T)
C     FOR NEON
      IF(T-44.4)1,2,2
    1 A=-8.9200910
      B=35.44150349
      C=-64.720906
      D=57.745619
      E=-20.25961912
      R=(1.0-T/44.4)**(1.0/3.0)
      DENR=1.0+A*R+B*R*R+C*R**3+D*R**4+E*R**5
      RSATD=10.**DENR
      DLIQNE=RSATD*.484*1000.028/20.183
      RETURN
```

```
    2 RSATD=1.
      DLIQNE=RSATD*.484*1000.028/20.183
      RETURN
C     UNITS ARE IN GM-MOLES/LITER
      END
      FUNCTION DPDDNE(DD,TT)
      DIMENSION G(18)
    3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      D1=DD
      T1=TT
      D2=D1**2
      D3=D2*D1
      D4=D3*D1
      D5=D4*D1
      T2=T1**2
      T3=T2*T1
      T4=T3*T1
      EX=EXP(A19*D2)
      EX1=EX*D1*2.*A19
      EX3=3.*D2*EX+D3*EX1
      EX5=5.*D4*EX+D5*EX1
      G(1)=D5*6. *A2
      G(2)=T1*D3*4.     *A3
      G(3)=D3*4.*A4
      G(4)=D4*5.*A5/T1
      G(5)=3.*D2*T2*A6
      G(6)=3.*D2*T1*A7
      G(7)=3.*D2*A8
      G(8)=3.*D2*A9/T1
      G(9)=3.*D2*A10/T2
      G(10)=D1*2.*T1*A11
      G(11)=D1*2.*A12
      G(12)=D1*2.*A13/T1
      G(13)=D1*2.*A14/T2
      G(14)=EX3*A15/T2
      G(15)=EX3*A16/T3
      G(16)=EX5*A17/T2
      G(17)=EX5*A18/T3
      P2=A1*T1
      DO 11 K=1,17
   11 P2=P2+G(K)
      DPDDNE=P2
C     CALCULATES THE FIRST DERIVATIVE OF PRESSURE WITH RESPECT TO
C     DENSITY ACCORDING TO DTRI4
      RETURN
      END
      FUNCTION ENT(D,T)
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      D1=D
      D2=D**2
      D3=D2*D
      D4=D3*D
      D5=D4*D
      T1=T
      T2=T*T
      T3=T2*T
      T4=T3*T
      EX=EXP(A19*D2)
      EXI1=EX/(A19*2.)
      EXI3=EX*D*D/(2.*A19)-(EX)/(2.*A19**2)
```

```
      ENT    =A5*D4/(T2*4.)-A3*D3/3.-A6*D2*T1
     1-A7*D2/2.+A9*D2/(T2*2.)+A10*D2/T3
     2-A11*D1+A13*D1/T2+A14*2.*D1/T3
     3+A15*2.*EXI1/T3+A16*3.*EXI1/T4
     4+A17*2.*EXI3/T3+A18*3.*EXI3/T4
     5-A1*ALOG(A1*T*D)
C     CALCULATES ENTROPY AT ONE LIMIT OF INTEGRATION,ISOTHERMAL,
C     ACCORDING TO DTRI4
      RETURN
      END
      FUNCTION ENTR(D,T)
C FOR NEON
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      D1=D
      D2=D**2
      D3=D2*D
      D4=D3*D
      D5=D4*D
      T1=T
      T2=T*T
      T3=T2*T
      T4=T3*T
      EX=EXP(A19*D2)
      EXI1=(EX-1.)/(2.*A19)
      EXI3=EX*D*D/(2.*A19)-(EX-1.)/(2.*A19**2)
      ENTR  =A5*D4/(T2*4.)-A3*D3/3.-A6*D2*T1
     1-A7*D2/2.+A9*D2/(T2*2.)+A10*D2/T3
     2-A11*D1+A13*D1/T2+A14*2.*D1/T3
     3+A15*2.*EXI1/T3+A16*3.*EXI1/T4
     4+A17*2.*EXI3/T3+A18*3.*EXI3/T4
     5-A1*ALOG(A1*T*D)
C     CALCULATES ENTROPY ALONG AN ISOTHERM FROM 0 TO A FINITE DENSITY
C     ACCORDING TO DTRI4
      RETURN
      END
C FOR NEON
      SUBROUTINE DATA N
C SETS THE CONSTANTS TO THE EQUATION OF STATE FOR NEON
    3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      A1=.0820535
      A2=.28010178E-07
      A3=.14244722E-05
      A4=-.14175051E-03
      A5=-.28070869E-04
      A6=-.10185146E-06
      A7=.42496352E-05
      A8=.25826979E-02
      A9=.12417383
      A10=-.62382566E-01
      A11=.17237659E-02
      A12=-.16730352
      A13=-.61781598E+01
      A14=.87257402E+02
      A15=.19355993E+02
      A16=-.84739643E+03
      A17=-.65528926E-01
      A18=    .23453113E+01
      A19=-.53186241E-02
      RETURN
      END
```

```
      FUNCTION PC(DD,TT)
C FOR NEON,P IS IN ATMOSPHERES,DD IN MOLES PER  LITER
C AND TT IS IN KELVIN
      DIMENSION G(18)
    3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
C     CALCUALTES PRESSURE ACCORDING TO DTRI4
      D1=DD
      T1=TT
      D2=D1**2
      D3=D2*D1
      D4=D3*D1
      D5=D4*D1
      D6=D5*D1
      T2=T1**2
      T3=T2*T1
      T4=T3*T1
      EX=EXP(A19*D2)
      Z=D1*A1*T1
      G(1)=D6*A2
      G(2)=T1*D4*A3
      G(3)=D4*A4
      G(4)=D5*A5/T1
      G(5)=D3*T2*A6
      G(6)=D3*T1*A7
      G(7)=D3*A8
      G(8)=D3*A9/T1
      G(9)=D3*A10/T2
      G(10)=D2*T1*A11
      G(11)=D2*A12
      G(12)=D2*A13/T1
      G(13)=D2*A14/T2
      G(14)=D3*EX*A15/T2
      G(15)=D3*EX*A16/T3
      G(16)=D5*EX*A17/T2
      G(17)=D5*EX*A18/T3
      P2=Z
      DO 11 K=1,17
   11 P2=P2+G(K)
      PC=P2
      RETURN
      END
      FUNCTION FNDTNE(P,D)
C SOLVES THE NEON EQUATION OF STATE FOR TEMPERATURE IN KELVIN
C FOR A INPUT OF PRESSURE IN ATMOSPHERES AND DENSITY IN MOL/L
      DATA(DTP=61.78),(DC=23.93)
      PP=P
      DD=D
      IF(DD.GT.DC)GO TO 1
      TT=44.4
      GO TO 2
    1 TT=24.54+(19.86/(DTP-DC))*(DTP-DD)
    2 DO 10 I=1,10
      P2=FNDPNE(DD,TT)
      IF(ABS(PP-P2)-1.E-7*PP)20,20,22
   22 DP=DPDTNE(DD,TT)
      CORR=(P2-PP)/DP
      IF(ABS(CORR)-1.E-5)20,20,10
   10 TT=TT-CORR
   20 FNDTNE=TT
      RETURN
```

```
      END
      FUNCTION FIND P(D,T)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DD=D
      TT=T
      IF(TT.LT.TCC)GO TO 10
    1 CALL PRESS(PP,DD,TT)
      FIND P=PP
      RETURN
   10 P=VPN(TT)
      DV=FIND D(P-.0001,TT)
      DL=FIND D(P+.0001,TT)
      IF(DD.LE.DV.OR.DD.GE.DL)GO TO 1
      PRINT 100,DV,DL,DD
      CALL PRESS(PP,DV,TT)
      FIND P=PP
      D=DV
      RETURN
  100 FORMAT(* THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO A *
     1/* DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION*
     2/* THE DENSITY OF THE SATURATED VAPOR IS *,F6.4,* MOLES/LITER*
     3/* THE DENSITY OF THE SATURATED LIQUID IS *,F8.4,* MOLES/LITER*
     4/* AND THE INPUT DENSITY IS *,F8.4,* MOLES/LITER*
     5/* SATURATED VAPOR IS ASSUMED*)
      END
      FUNCTION DPDTNE(D,T)
C GIVES THE FIRST DERIVATIVE OF PRESSURE WITH RESPECT TO
C TEMPERATURE FOR NEON
C INPUT PARAMETERS ARE DENSITY(MOLES/LITER) AND TEMPERATURE(K)
      DIMENSION G(18)
    3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      D1=DD
      T1=TT
      D2=D1**2
      D3=D2*D1
      D4=D3*D1
      D5=D4*D1
      D6=D5*D1
      T2=T1**2
      T3=T2*T1
      T4=T3*T1
      EX=EXP(A19*D2)
      G(1)=0
      G(2)=D4*A3
      G(3)=0
      G(4)=-D5*A5/T2
      G(5)=2.*D3*T1*A6
      G(6)=D3*A7
      G(7)=0
      G(8)=-D3*A9/T2
      G(9)=-2.*D3*A10/T3
      G(10)=D2*A11
      G(11)=0
      G(12)=-D2*A13/T2
      G(13)=-2.*D2*A14/T3
      G(14)=-2.*D3*EX*A15/T3
      G(15)=-3.*D3*EX*A16/T3
      G(16)=-2.*D5*A17*EX/T3
      G(17)=-3.*D5*A18*EX/T4
      P2=D1*A1
```

```
      DO 11 K=1,17
   11 P2=P2+G(K)
      DPDTNE=P2
      RETURN
      END
      FUNCTION FNDTHE(P,D)
C SOLVES THE EQUATION OF STATE  FOR HELIUM
C   FOR A TEMPERATURE(IN KELVIN) GIVEN A PRESSURE IN ATM
C AND A DENSITY IN MOLES/LITER
      DATA(DTP=36.514),(DC=17.399)
      PP=P
      DD=D
      IF(DD.GT.DC)GO TO 1
      TT=5.201
      GO TO 2
    1 TT=2.177+(3.024/(DTP-DC))*(DTP-DD)
    2 DO 10 I=1,10
      P2=FNDPHE(DD,TT)
      IF(ABS(PP-P2)-1.E-7*PP)20,20,11
   11 DP=DPDTHE(DD,TT)
      CORR=(P2-PP)/DP
      IF(ABS(CORR)-1.E-5)20,20,10
   10 TT=TT-CORR
   20 FNDTHE=TT
      RETURN
      END
      FUNCTION FINDT(P,D)
C SOLVE THE THIRTY TWO TERM EQUATION OF STATE FOR TEMPERATURE
C IN KELVIN GIVEN A PRESSURE IN ATMOSPHERES  AND A DENSITY IN
C MOLES/LITER
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      PP=P
      DD=D
      IF(P.GE.PCC/1.01325)GO TO 1
      TSAT=FINDTV(PP)
      DV=FIND D(PP-.00001,TSAT)
      DL=FIND D(PP+.0001,TSAT)
      IF(DD.GT.DV.AND.DD.LT.DL)GO TO 30
      TT=TSAT
      GO TO 2
    1 TT=TCC
    2 DO 10 I=1,10
      CALL PRESS(P2,DD,TT)
      IF(ABS(PP-P2)-1.E-7*PP)20,20,11
   11 CALL DPDT(DP,DD,TT)
      CORR=(P2-PP)/DP
      IF(ABS(CORR)-1.E-5)20,20,10
   10 TT=TT-CORR
   20 FINDT=TT
      RETURN
   30 FINDT=TSAT
      D=DV
      PRINT 100,DV,DL,DD
  100 FORMAT(* THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO*
     1/* A DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION*
     2/* DENSITY OF THE SATURATED VAPOR IS*,F8.4,* MOLES/LITER*
     3/* DENSITY OF THE SATURATED LIQUID IS*,F8.4,* MOLES/LITER*
     4/* INPUT DENSITY IS*,F8.4,* MOLES/LITER*
     5/* SATURATED VAPOR CONDITIONS ARE ASSUMED*)
      RETURN
      END
```

```
      FUNCTION CPOSNE(T)
C     CALCULATES THE INTEGRAL OF (CP/T)DT FROM ,TO,TO T FOR NEON
C     TO IS 27.092 AND CP IS AT ZERO PRESSURE,5/2R
      CP  =8.31434*ALOG(T/27.092)*2.5
      CPOSNE=CP
      RETURN
C     UNITS ARE JOULES/MOLE-K
      END
      FUNCTION CPOHNE(T)
C     CALCULATES THE INTEGRAL OF (CPT)DT FROM ,TO,TO T FOR NEON,CP AT
C     ZERO PRESSURE, ,TO, IS 27.092
      CP  =8.31434*(T-27.092)*2.5
      CPOHNE=CP
      RETURN
C     UNITS ARE JOULES/MOLE-K
      END
      FUNCTION FNDDNE(PP,TT)
C SOLVES THE EQUATION OF STATE FOR NEON FOR DENSITY (MOLES/L)
C GIVEN A PRESSURE IN ATM AND A TEMPERATURE IN KELVIN
      P=PP
      T=TT
      D=20.
      IF(TT.GT.44.4)GO TO 2
      PSAT=VPNNE(TT)
      D=.001
      IF(PSAT.GE.PP)GO TO 2
      D=DLIQNE(T)+1.
    2 CONTINUE
      DO 10 I=1,50
      P2=PC(D,T)
      IF(ABS(P-P2)-1.E-6*P)11,11,1
    1 DP=DPDDNE(D,T)
      IF(ABS((P-P2)/DP)-1.E-6*D)11,11,10
   10 D=D-(P2-P)/DP
      FNDDNE=0
      RETURN
   11 FNDDNE=D
      RETURN
      END
      FUNCTION ENTH  (P,D,T)
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
     1,A18,A19
      D1=D
      D2=D**2
      D3=D2*D
      D4=D3*D
      D5=D4*D
      T1=T
      T2=T*T
      T3=T2*T
      T4=T3*T
      EX=EXP(A19*D2)
      EXI1=EX/(A19*2.)
      EXI3=EX*D*D/(2.*A19)-(EX)/(2.*A19**2)
      ENTH  =P/D+A4*D3/3.+A5*D4/(T1*2.)
     1-A6*D2*T2/2.+A9*D2/T1+3.*A10*D2/(T2*2.)
     2+A12*D1+2.*A13*D1/T1+3.*A14*D1/T2
     3+3.*A15*EXI1/T2+4.*A16*EXI1/T3
     4+3.*A17*EXI3/T2+4.*A18*EXI3/T3
     6+A2*D5/5.+A8*D2/2.
C     CALCUALTES ENTHALPY AT ONE LIMIT OF INTEGRATION ACCORDING
C     TO DTRI4,ISOTHERMAL
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```
      RETURN
      END
      FUNCTION VPTENE(PP)
C     SOLVES THE VAPOR PRESSURE EQUATION FOR TEMPERATURE GIVEN A PRESSURE
C     THE FLUID IS NEON  AND THE UNITS ARE ATMOSPHERES AND KELVINS
      T=44.
      PCAL=VPNNE(T)
      P=PP
   13 DO 10 I=1,50
      DP=DVPNNE(T)
      DEL=(PCAL-P)/DP
      T=T-DEL
      PCAL=VPNNE(T)
      IF(ABS(P-PCAL)-.000001*P)11,11,2
    2 IF(ABS(DEL)-.000001*T)11,11,10
   10 CONTINUE
   11 VPTENE=T
      RETURN
      END
      FUNCTION ENTHNE(P,D,T)
C     CALCULATES THE ENTHALPY FOR NEON IN JOULES/MOLE, GIVEN THE PRESSURE
C     IN ATMOSPHERES,THE DENSITY IN MOLES/LITER,AND THE TEMPERATURE IN
C     KELVINS
      DATA(H0=.18638645E+4)
      IF(T.LT.44.4)GO TO 52
    1 ENTHNE=H0+CP0HNE(T)+ENTHA(P,D,T)*101.325
      RETURN
   52 PSAT=VPNNE(T)
      PSAT=PSAT-.0001
      DVAP=FNDDNE(PSAT,T)
      IF(D.LE.DVAP)GO TO 1
      PSAT=PSAT+.0002
      DLIQ=FNDDNE(PSAT,T)
      H1=H0+CP0HNE(T)+ENTHA(PSAT,DVAP,T)*101.325
      H2=DVPNNE(T)*(1./DVAP-1./DLIQ)*T*101.325
      H3=(ENTH(P,D,T)-ENTH(PSAT,DLIQ,T))*101.325
      ENTHNE=H1-H2+H3
      RETURN
      END
      FUNCTION ENTRNE(D,T)
C     CALCULATES THE ENTROPY FOR NEON GIVEN DENSITY IN MOLES PER LITER
C     AND TEMPERATURE IN KELVINS, OUTPUT IS IN JOULES/MOLE-K
      DATA(S0=68.52101455)
      IF(T.LT.44.4)GO TO 52
    1 ENTRNE=S0+CP0SNE(T)+ENTR(D,T)*101.325
      RETURN
   52 PSAT=VPNNE(T)
      PSAT=PSAT-.0001
      DVAP=FNDDNE(PSAT,T)
      IF(D.LE.DVAP)GO TO 1
      PSAT=PSAT+.0002
      DLIQ=FNDDNE(PSAT,T)
      S1=S0+CP0SNE(T)+ENTR(DVAP,T)*101.325
      S2=DVPNNE(T)*(1./DVAP-1./DLIQ)*101.325
      S3=(ENT(D,T)-ENT(DLIQ,T))*101.325
      ENTRNE=S1-S2+S3
      RETURN
      END
      FUNCTION VPNNE(T)
C     GIVES A VAPOR PRESSURE FOR NEON IN ATMOSPHERES GIVEN A TEMP IN K
      Q    =(7.46116 -106.090/T -.0356616*T + .000411092*T*T)
      BVAP=(10.0**Q/760.0)
```

```
      VPNNE=BVAP
      RETURN
      END
      FUNCTION DVPNNE(T)
C     DERIVATIVE OF THE VAPOR PRESSURE CURVE FOR NEON
      Q=106.090/T**2-.0356616+2.*.000411092*T
      DVPNE=VPNNE(T)*Q*2.302585093
      DVPNNE=DVPNE
      RETURN
      END
/
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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The thermodynamic and transport properties of selected cryogens have been programmed into a series of computer routines. Input variables are any two of P, ρ or T in the single phase regions and either P or T for the saturated liquid or vapor state. The output is pressure, density, temperature, entropy, enthalpy for all of the fluids and in most cases specific heat capacity and speed of sound. Viscosity and thermal conductivity are also given for most of the fluids. The programs are designed for access by remote terminal; however, they have been written in a modular form to allow the user to select either specific fluids or specific properties for particular needs.

The program includes properties for hydrogen, helium, neon, nitrogen, oxygen, argon, and methane. The programs include properties for gaseous and liquid states usually from the triple point to some upper limit of pressure and temperature which varies from fluid to fluid. Computer listings of the FORTRAN four codings are presented. Copies of the programs may be obtained from either the Thermophysical Properties Division of the National Bureau of Standards at Boulder, Colorado, or from Walter Scott at the NASA-Johnson Space Center in Houston, Texas.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Argon; computer programs; density; enthalpy; entropy; equation of state; heat capacity at constant pressure; heat capacity at constant volume; helium; hydrogen; methane; neon; nitrogen; oxygen; thermal conductivity; velocity of sound; viscosity.

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